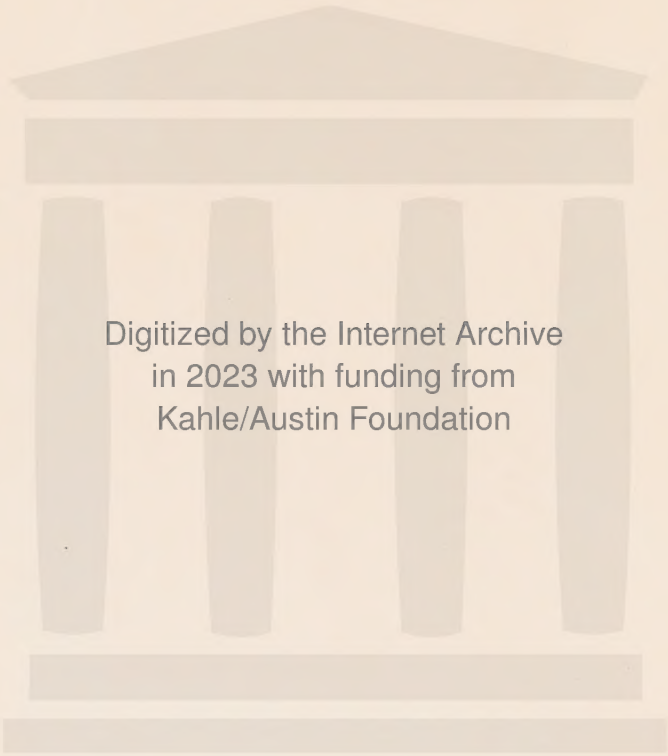
ECONOMIC CROPS

VOLUME II

APPLES AND APPLE PRODUCTS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APPLES AND APPLE PRODUCTS

ECONOMIC CROPS

A series of monographs on the chemistry, physiology, and technology of food and food products

Z. I. KERTESZ, Editor

VOLUME I

BANANAS
By Harry W. von Loesecke

VOLUME II

APPLES AND APPLE PRODUCTS
By R. M. Smock and A. M. Neubert

APPLES AND APPLE PRODUCTS

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INTRODUCTION TO THE SERIES

The widespread application of chemical analysis in plant research and in the increasing production of processed foods of plant origin has resulted in the accumulation of a wealth of analytical data on the chemical constituents present in plant tissues. Such data are now sought by workers in many branches of scientific research and technology, by chemists, physiologists, botanists, plant breeders, nutritionists, food manufacturers, and others. As this information became available, the great variability in the chemical composition of food crops became increasingly clear. Indeed, it is now known that the kind of soil used, cultural conditions, climate, seasonal influences, variety, the time and method of harvesting, conditions of storage and handling, and many other known and yet unknown factors cause variations which will often play an important part in the composition, behavior, and utility of food crops. These variations are often of such magnitude that the meaning and usefulness of average values is limited, and compilations of analytical results without any exact characterization of the plant tissues used are also of little value. Consequently, the need for critical and systematic discussions of the role of the factors causing variations in the chemical composition and biochemical behavior of economically important food crops has become increasingly appreciated.

Those interested in the composition and behavior of food crops might be arbitrarily grouped into two major categories. The first includes workers interested in the production of crops: soil scientists, farmers, horticulturists, physiologists, ecologists, and many other groups might be placed in this first category, and plant pathologists and entomologists may also be listed with others interested in the production problems. The second classification includes those interested in the utilization of crops: the food processors and, ultimately, the nutritionists.

It has been a rather common experience to find a lack of understanding of the other's problems in both these groups. This is only natural, for those engaged in almost any of these activities must be specialists, often dealing with only a single phase of our elaborate food production schemes. Yet, time and again, the lack of an even superficial knowledge of the difficulties facing the food processor have limited the usefulness of those dealing with the various aspects of the crop production. Perhaps even more difficulty is caused by the reverse—the absence of sufficient appreciation by food processors of the problems in the large-scale production of uniform crops of high quality.

It is for such reasons that these volumes are organized in a manner to aid both groups. While chemical composition and biochemical and physiological behavior are the central themes, the books also deal with botanical aspects and production factors, on one hand, and with the methods of utilization and processing, on the other. The discussions are not written for the specialist; the aim is to complement the picture for persons in either group interested in chemical composition and the causes of variability.

Dealing with any topic in such a manner sets the authors to a most difficult task. It is impossible to find authors who are experts in all the various phases of agriculture, physiology, chemistry, and processing problems. The writing of these books has been entrusted to scientists and technologists who have had extensive experience with the crop in question and who, in addition to being specialists in certain aspects, will also appreciate the intricate relationship between crop production and processing technology. Needless to say, the assignment of writing a book on such a broad scope requires much interest, restraint, and a spirit of cooperation from the author.

Z. I. KERTESZ

Geneva, New York

PREFACE

It is believed that this is the first attempt to write a book covering the apple fruit after harvest. The chemistry, physiology, and processing of just this one fruit are covered. Of course, some aspects of fruit behavior and treatments prior to harvest may affect its behavior after harvest, and these are included.

This volume is designed to serve both as a text and as a reference book. It may be used as a text for college courses covering the handling, storage, and utilization of fruits. It is also intended as a reference book for persons interested in the handling, storage, and processing of the apple. It is not intended as a text or reference book on the production aspects of this fruit. It is presumed that the horticulture student would have considerably more background in this topic than is offered in this text.

References have been cited to establish authority and to assist the reader who may wish to read more fully on any particular topic. Needless to say, citations from all the voluminous literature covering the subject have not been made.

The authors are indebted to the numerous research workers whose work has been cited and drawn upon very freely. They also wish to express their appreciation to reviewers of one or more chapters of the book. The authors wish, however, to assume full responsibility for the statements made in the text. Those who have reviewed portions or all of the text are: Professors L. H. MacDaniels, D. G. Clark, and D. Boynton of Cornell University; F. W. Southwick of the University of Massachusetts; F. W. Allen and W. O. Williams of the University of California; J. R. Matchett and M. E. Davis of the Western Regional Research Laboratory; J. J. Willaman and C. H. Hills of the Eastern Regional Research Laboratory. The authors wish to thank Dr. Z. I. Kertesz for editing the book and integrating it with the other volumes in the series on "Economic Crops."

R. M. Smock
A. M. Neubert

May, 1950

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CHAPTER I

HISTORY AND DISTRIBUTION OF THE APPLE

A. History of the Apple

Early History. The original home of the apple (*Malus sylvestris*) is not known but it is thought to be indigenous to the region south of the Caucasus, from the Persian province of Ghilan on the Caspian sea to Trebizond on the Black Sea. It has probably existed from prehistoric times in both the wild and cultivated states in Europe from the Caspian Sea to the Atlantic Ocean. In early times it was not found in the northernmost and coldest parts of Europe, however.[1] Variety lists of apples were available as early as 100 B.C.

American History. Before the apple was brought to America it had been doubtlessly cultivated in Europe for at least 2000 years. Prior to the colonization of America, variety selection from seedlings had been going on and considerable grafting of known varieties was being done in Europe. Both seeds of European varieties and grafted trees were brought to this country by early American colonists. Governor Endicott of Massachusetts introduced apples to this country, but they were doubtless mostly trees grown from seed.

It was at Flushing, Long Island, in one of the Huguenot settlements that the Prince Nurseries were established about 1730. It was near these nurseries that the Yellow Newtown Pippin apple originated. As early as 1647 there were recorded cases of apples having been grafted upon seedling rootstocks in Virginia. William Fitzhugh mentioned a large orchard of 2500 apple trees which were "mostly grafted."[2]

Since transportation facilities were crude in early colonial days there was little shipment of apples to distant markets. However, there

[1] J. R. Magness, *U. S. D. A. Farmers' Bull.*, 1883, 1941.
[2] S. A. Beach, *Apples of New York.* N. Y. State Dept. Agr., Albany, 1905, pp. 3–18.

was some shipping of apples down the Hudson River to New York City from the upper Hudson Valley. Apples not consumed at home were disposed of in the manufacture of cider, hard cider, boiled cider, and vinegar. Some apples were also dried.[2] For the drying of apples the kitchen stove was usually surrounded with festoons of quartered fruit which had been strung on strings. Sometimes the prepared fruit was spread on racks above or below the kitchen stove.[2]

In his history of the early apple industry, Taylor[3] says:

"Trade in this fruit with the East Indies probably developed early in the eighteenth century though we have no record of shipments until 1741. At that time apples were exported from New England to the West Indies in considerable abundance. No transatlantic shipment has been disclosed earlier than that of a package of Newtown Pippin apples from the crop of 1758 sent to Benjamin Franklin while in London."

By 1773 apples from America were found in the London markets.

"Statistics are lacking on the subject until 1821 when the total export of fruit consisted of 68,443 bushels of apples valued at $39,966."[3]

From the early plantings of seedling and grafted trees in the eastern United States, apple trees were rapidly disseminated to the more westerly portions of the young country. Indians, traders, and missionaries carried seeds into the wilderness far beyond the white settlements.[2] Among the most famous of the distributors of apple seeds was the almost legendary figure Johnny Appleseed. This man, whose real name was John Chapman, was a missionary of the Swedenborgian faith, who started nurseries of young apple trees in Ohio and Indiana with seeds which he collected from cider mills in older settlements. In winter he was said to have travelled barefoot through the snow distributing apple seeds to the early settlers of western Ohio and eastern Indiana. He often left Indian converts tending the nurseries which he planted.[4]

Reports of General Sullivan's expedition in 1779 against the Cayuga and Seneca Indians describe seedling apple trees around the Indian villages. As late as 1900 many of these old Indian apple trees were still standing around New York State.[2]

In 1847 Henderson Lewelling took a load of nursery stock by ox

[3] W. A. Taylor, "The Fruit Industry and Substitution of Domestic for Foreign Grown Fruits," *U. S. D. A. Yearbook,* 1897, 1898, pp 308–344.

[4] W. Paddock, *Johnny Appleseed by One Who Knew Him.* Heer, Columbus, Ohio, 1922.

team and wagon from Iowa to Oregon. It was from this early introduction of stock that the early plantings in the Pacific Northwest were established.[1]

During the nineteenth century apple growing in the United States was largely a farm operation. Many farms had from a few trees to a few acres with trees being given no intensive care. Spraying was an unknown practice and few trees were fertilized unless it was with barnyard manure. Many if not most of the orchards had livestock grazing in them. Because there were no large intensified apple growing areas and because the apple industry was still young there were no severe insect and disease problems. Nevertheless, most of the apples arriving on the market were expected to have some insect and disease blemishes.

Although certain sections such as western New York and Virginia came to be known as apple growing areas during the latter part of the nineteenth century, apple tree planting was general throughout the United States.[1] The census for 1900 reported over two million bearing apple trees or almost two and one half times as many as reported in 1935. This large number was due to the quantity of apple trees in small numbers on many farms. By 1935 most of the apple industry was confined to localized and concentrated growing areas. The problem of insect and disease control has become too serious to justify many small farm orchards. Only the grower equipped with suitable spray equipment and with the time to do a thorough job of spraying can be found growing apples successfully at the present time. Spraying did not become a general practice until the early part of the twentieth century.

The development of intensive orchard areas in the irrigated districts of Washington, Oregon, and California did not take place until the early part of the twentieth century. The Hood River Valley of Oregon was among the first sections to become famous as an apple growing area in the west about 1910.[1] Extensive plantings in the Wenatchee and Yakima Valleys of Washington were started somewhat after that time.

Varietal History. Of course, most of the early orchards in this country were composed of seedling trees. It has been pointed out that some of the early trees were grafted, yet doubtlessly a very large percentage of the trees in the early settlements were seedling trees. From among the countless numbers of trees that were soon growing

in the fence rows and pastures of the eastern United States, selections of the superior ones were made. Scion wood was taken from the superior fruiting trees and propagated on other seedling trees. It is interesting to note that most of the varieties now growing in the United States have been propagated from those early seedlings. Among some of the more famous examples are Baldwin, Northern Spy, Spitzenburg, and Yellow Newtown Pippin. A few varieties like Duchess of Oldenburg were imported directly from Europe and more recently varieties have been introduced as a result of systematic breeding.

Breeding work on apples is still comparatively young. While it has been going on experimentally since the latter part of the nineteenth century, very few varieties have been introduced as a result of controlled breeding. Probably the most widely known and disseminated of the actual controlled crosses is the Cortland (McIntosh and Ben Davis). While the Cortland was introduced about 1900 it is still considered a "new" variety. This is true because it takes so long to evaluate a variety. Other varieties introduced in the more recent past like Macoun, Kendall, and Franklin must stand the test of the years with regard to average annual yield, tendency to biennial bearing, strength of tree, winter hardiness, disease and insect resistance, necessity of thinning, date of blooming, age at which it starts to bear, and many other considerations.

Although apple trees which are propagated vegetatively by budding and grafting normally transmit all the characteristics of the parent propagating tree, occasionally somatic mutations occur in the vegetative parts of the plants. As a result of these mutations changes in the characteristics of the variety (even though vegetatively propagated) sometimes appear. Occasional branches are found in trees on which the fruit varies in some respects such as more or less color, larger size, earlier or later ripening, and other characteristics. These somatic mutations are commonly called "sports." Search for new and interesting sports has resulted in finding a number of improvements in some of our named varieties. The most commonly sought for sport is an improvement in fruit color. Many varieties now have "strains" of improved color. Unfortunately, not only the color of the fruit necessarily mutates in these sports. Accompanying the improved color there may be a decrease in keeping quality or a lessening of some other desirable characteristic.

B. World Distribution of Apples

The most important and probably the most widely grown tree fruit in the world is the apple. While most apples are grown for dessert or cooking purposes throughout the temperate regions of the world, many in Germany, France, and the United Kingdom are produced for cider (fermented apple juice) and are too sour for eating purposes. The total annual apple production in 31 countries from 1931–1936 was about 416 million bushels.[5] About one third of all the apples grown are produced in the United States. France and Germany follow in importance in the production of this fruit. Canada, Australia, Italy, Switzerland, England, and Wales are among the other important apple producing countries. It must be remembered that apples are grown in most temperate climates and many other countries like Argentina, New Zealand, and South Africa produce commercial quantities of apples. At the higher altitudes of some of the countries with a less temperate climate such as Mexico, apples are also grown. See Table A-2 in appendix for the production of apples in the various countries of the world.

C. Distribution of the Apple Industry in the United States and Canada

New York-New England District. In New York the largest fruit growing area is in western New York along the shores of Lake Ontario. A low ridge resulting from the old lake shore line paraliels the present shore from 8 to 15 miles inland. This ridge and the land between it and the lake are intensively planted to apples and other fruit. The counties included in this apple growing section are Niagara, Orleans, Monroe, and Wayne. In the *Hudson Valley* section apples are grown on both sides of the river primarily in the central or middle portion of the valley. The counties primarily involved include Dutchess, Columbia, Ulster, and Orange. In the *Champlain Valley* section apples are grown on both the New York and Vermont sides of Lake Champlain. Some apples are grown in the Finger Lakes section of New York along the shores facing Lakes Cayuga, Seneca, and Keuka.

In New England apples are grown in *Maine* in the southern and eastern parts of the state, which are partially protected from severe

[5] A. C. Edwards and S. I. Katz, *U. S. D. A. Bur. Agr. Econ. F.S., 75,* 1938.

cold from the north and west by mountains.[6] In southern *New Hampshire* similar protection is offered by the White and the Green Mountains. Apples are planted in scattered sections of Connecticut, Massachusetts and Rhode Island.

Middle Atlantic District. This section includes New Jersey, Delaware, Maryland, West Virginia, Virginia, and the Carolinas. Northern Georgia is the southern boundary for successful apple growing. The winters are not cold enough to break the rest period in the Far South. In fact, the more successful apple regions in states like the Carolinas are at high elevations where the mean average summer temperature is below 75°F. The most intensively developed apple district of this section is in the upper Potomac drainage basin and includes south central Pennsylvania, western Maryland, eastern West Virginia, and northern Virginia. This section is called the *Cumberland-Shenandoah* area. In the Coastal Plain Belt of southern New Jersey, Delaware, and eastern Maryland, early varieties are grown primarily.

Middle Western District. There are some wide climatic variations in this general district. In the *Ohio Basin* section apples are grown on both sides of the Ohio River in Ohio, Kentucky, Indiana, and Illinois. In the *Ozark region* is included southwestern Missouri, eastern Oklahoma, and northwestern Arkansas. In the Missouri Valley section lie areas in Missouri, northeastern Kansas, and southeastern Nebraska. Apple growing in northern Ohio, Michigan, and Wisconsin involves different varieties than in the other areas in this middle western district.

Western District. In Washington one of the main areas is the *Wenatchee* section. This district just east of the Cascade Mountains in north central Washington is in the Columbia River Valley. The *Yakima Valley* is east of the Cascade range of mountains in the valley of the Yakima River. There are smaller areas of apple production in the Walla Walla and White Salmon districts and in the valley of the Spokane River. In Oregon the main district is in the valley of the Hood River. In California the principal districts are centered around *Sebastopol* and *Watsonville.* The principal apple producing districts in Idaho are in the valleys of the Boise and Payette Rivers and other tributaries of the Snake River. Most of the apples in Utah are produced adjacent to the Great Salt Lake. The main center of apple production in Colorado is the valley of the Grand River and its tributaries in the west central part of the state.[6]

[6] J. R. Magness, *U. S. D. A. Farmers' Bull.*, 1883, 1941.

Canadian Districts. There is a large apple growing section in the Annapolis Valley of Nova Scotia. A large producing area in British Columbia is very similar to the Oregon and Washington districts. Apples are grown along the shores of Lakes Erie and Ontario in Ontario and in the provinces of New Brunswick and Quebec.

D. Distribution of Varieties

Within a given district there are bound to be varying climatic conditions which favor one variety as compared to another. For example, in New York the Delicious apple fares better in the Hudson Valley section than in the western part of the state. McIntosh does better in the Champlain Valley than it does in the lower Hudson Valley. Hence it is difficult to give a very accurate description of the distribution of various varieties. The following outline merely suggests the main varieties that are found in the main apple growing sections. For actual production of various varieties in the various states see Table A-1 in the appendix.

New York and New England. McIntosh, Rhode Island Greening, Northern Spy, Wealthy, Cortland, Oldenburg, Baldwin, Ben Davis, Delicious, Golden Delicious, Rome Beauty, and Fameuse.

Middle Atlantic. York Imperial, Stayman Winesap, Winesap, Delicious, Rome Beauty, Ben Davis, Grimes Golden, Jonathan, Yellow Transparent, and Albermarle Pippin (Yellow Newtown).

Middle Western. Rome Beauty, Grimes Golden, Jonathan, Stayman Winesap, Delicious, Winesap, Ben Davis, Yellow Transparent, and Golden Delicious. In the northern part of this district as in Michigan, Wisconsin, and northern Ohio, other varieties such as McIntosh and Wealthy are grown.

Western District. In Washington the Delicious variety including its red sports led in number of trees in 1936 with 35% of the total. Winesap was second with 33%, followed by Jonathan with 11%, Rome Beauty with 8%, and Yellow Newtown with 3.[6] In Oregon Yellow Newtown is by far the leading variety with Delicious, Esopus Spitzenburg, Rome Beauty, and Ortley following in importance. In Utah, Idaho, and Colorado the varieties are Delicious, Rome Beauty, Jonathan, Winesap, with McIntosh being grown in some of the cooler sections. In California the main variety in the Sebastapol section is the Gravenstein with some Rome Beauty, Jonathan, Delicious, and Yellow Newtown. In the Watsonville area of California the main varieties are the Yellow Newtown and the Yellow Belleflower.

Canadian Districts. In the British Columbia sections the same varieties that are grown in Washington and Oregon are produced. In Nova Scotia quite a number of English varieties like Coxes Orange are grown but these are being supplanted rapidly by varieties like Northern Spy, McIntosh, Fameuse, Wagner, and Golden Russet. Gravenstein is one of the main varieties of this section.

In the Ontario section varieties include Yellow Transparent, Oldenburg, Wealthy, Alexander, Northern Spy, Fameuse, Baldwin, and Rhode Island Greening. The varieties in the New Brunswick and Quebec sections are much the same as those grown in the Ontario areas.

CHAPTER II

VARIETIES OF APPLES

There are well over 1800 named varieties of apples.[6] From this tremendous list must be selected those varieties which best serve the purposes of the commercial fruit grower, the processor, and the consumer.

There is no such thing as the "perfect" apple variety. Every variety has some or possibly many faults. In selecting varieties for planting the fruit grower tries to select those which have the fewest faults. There is also the matter of personal tastes in apple varieties. One variety might have high quality in the judgment of some people and yet be of low quality to others.

Apple varieties differ tremendously in both tree and fruit characteristics. Tree characteristics are of prime interest to the grower even though they may not be to the consumer. A given variety like Northern Spy may have very high dessert quality and bring a high price on the market and yet growers might make more money on other varieties which have fewer undesirable tree characteristics.

A. Tree Characteristics

Among the tree characteristics which must be considered in evaluating varieties are the following (see also Tables 1 and 2).

Yield. One of the main factors which determines cost of production of apples is yield. While yield may vary from section to section for a given variety, even when placed in the most ideal growing section for that variety the yield may be very disappointing.

Age of Bearing. Some apple trees like McIntosh may start to bear when they are seven or eight years old. Other varieties like Northern Spy may not start to bear until they are 12 to 15 years old.

Shape and Size of Tree. Some varieties grow larger than others and hence have to be planted farther apart. Some varieties are mechanically very strong and others are very weak. Some require much more pruning than others.

TABLE 1. TREE CHARACTERISTICS OF LEADING APPLE VARIETIES[6]

Variety	Shape of tree	Vigor of tree	Ultimate size of tree	Age to first bearing	Tendency to annual or biennial production
Delicious	Upright spreading	Vigorous	Large	Medium (5–8 yrs.)	Intermediate
Winesap	Spreading	Medium	Medium	Medium (6–8 yrs.)	Intermediate
Jonathan	Spreading	Medium	Medium	Early (4–6 yrs.)	Annual
Baldwin	Upright spreading	Very vigorous	Large	Medium to rather late (8–10 yrs.)	Biennial
Stayman Winesap	Spreading	Vigorous	Large	Early (4–6 yrs.)	Annual
Ben Davis	Upright spreading	Medium	Medium	Early (4–6 yrs.)	Annual
Rome Beauty	Spreading	Medium	Medium to small	Early (4–6 yrs.)	Annual
York Imperial	Upright spreading	Vigorous	Large	Medium (6–8 yrs.)	Biennial
McIntosh	Spreading	Vigorous	Large	Early (4–6 yrs.)	Annual
Grimes Golden	Spreading	Medium	Medium to large	Medium (6–8 yrs.)	Intermediate
Yellow Newtown	Upright spreading	Medium	Medium	Medium to late (8–10 yrs.)	Biennial
Wealthy	Upright spreading	Medium	Medium to small	Early (4–6 yrs.)	Biennial
Yellow Transparent	Upright	Medium	Medium to small	Early (4–6 yrs.)	Biennial
R. I. Greening	Spreading	Vigorous	Medium to large	Medium (6–8 yrs.)	Intermediate
Northern Spy	Upright	Medium	Medium to large	Very late (10–14 yrs.)	Intermediate
Gravenstein	Upright spreading	Vigorous	Medium to large	Medium (6–8 yrs.)	Annual
Oldenburg (Duchess)	Spreading	Medium	Medium	Early (4–6 yrs.)	Intermediate
Arkansas	Upright spreading	Vigorous	Large	Medium to late (8–10 yrs.)	Biennial
Golden Delicious	Spreading	Medium	Medium	Early (4–6 yrs.)	Intermediate
Esopus Spitzenburg	Upright	Vigorous	Large	Medium (6–8 yrs.)	Intermediate
Wagener	Very upright	Medium	Medium	Early (4–6 yrs.)	Intermediate
Stark	Upright spreading	Vigorous	Large	Medium (6–8 yrs.)	Intermediate
Winter Banana	Spreading	Medium	Medium	Early (4–6 yrs.)	Intermediate
Cortland	Spreading	Medium	Medium	Early (4–6 yrs.)	Annual

TABLE 2. Relative Susceptibility of Important Apple Varieties to Principal Diseases and Spray Injury[6]

Variety	Scab	Bitter rot	Fire blight	Cedar rust	Spray injury
Delicious	Very susceptible	Resistant	Very resistant	Very resistant	Resistant
Winesap	Very susceptible	Very resistant	Very resistant	Very resistant	Susceptible
Jonathan	Resistant	Susceptible	Very susceptible	Very susceptible	Susceptible
Baldwin	Susceptible	Resistant	Very susceptible	Very resistant	Susceptible
Stayman Winesap	Very susceptible	Resistant	Resistant	Very resistant	Resistant
Ben Davis	Very susceptible	Very susceptible	Resistant	Resistant	Very susceptible
Rome Beauty	Very susceptible	Resistant	Susceptible	Very susceptible	Resistant
York Imperial	Resistant	Resistant	Susceptible	Susceptible	Susceptible
McIntosh	Very susceptible	—	Susceptible	Very resistant	Resistant
Grimes Golden	Very resistant	Very susceptible	Susceptible	Resistant	Susceptible
Yellow Newtown	Susceptible	Very susceptible	Susceptible	Very resistant	Susceptible
Wealthy	Susceptible	Susceptible	Very susceptible	Very susceptible	Resistant
Yellow Transparent	Resistant	Susceptible	Very susceptible	Resistant	Resistant
R. I. Greening	Susceptible	Susceptible	Susceptible	Resistant	Resistant
Northern Spy	Susceptible	Susceptible	Susceptible	Resistant	Susceptible
Gravenstein	Susceptible	—	Susceptible	Very resistant	Resistant
Oldenburg (Duchess)	Resistant	—	Very susceptible	Very resistant	Resistant
Golden Delicious	Susceptible	Very susceptible	—	Susceptible	Very susceptible
Esopus Spitzenburg	Susceptible	—	Very susceptible	Susceptible	Susceptible
Wagener	Resistant	—	Very susceptible	Very resistant	Resistant
Stark	Susceptible	Susceptible	Susceptible	Susceptible	Resistant
Winter Banana	Resistant	Resistant	Resistant	Very susceptible	Resistant
Cortland	Susceptible	—	Resistant	Susceptible	Resistant

TABLE 3. PRICE[a] TRENDS OF APPLE VARIETIES AT NEW YORK CITY[7]

Variety	Long-time trend[b] Number of years	Long-time trend[b] Yearly price change	Recent trend, 1930–39[b]	Average price, 1930–39
Upward price trend				
Delicious	20	+1.6	Up	126
Grimes Golden	23	+0.8	Down	70
Northern Spy	60	+0.7	Up	130
Wagener	20	+0.7	None	82
Fall Pippin	61	+0.2	Down	98
R. I. Greening	61	+0.1	None	107
No price trend				
Baldwin	61	0	None	106
Stark	25	0	None	94
Twenty Ounce	61	0	None	93
Coddling	59	0	Down	90
Hubbardston	55	0	Down	83
Downward price trend				
Yellow Transparent	30	−0.2	None	86
Tompkins King	61	−0.2	None	97
Maiden Blush	61	−0.4	Down	62
Wealthy	37	−0.5	Down	84
Rome Beauty	58	−0.5	None	109
Jonathan	50	−0.5	None	87
Alexander	61	−0.6	Down	74
Fameuse	56	−0.7	Down	104
Northwest Greening	26	−0.7	Down	93
Winesap	50	−0.7	Down	110
Spitzenburg	61	−0.7	Down	146
York Imperial	45	−0.8	Down	108
Black Twig	25	−0.8	None	76
Stayman Winesap	25	−0.8	Up	88
Ben Davis	58	−0.9	None	72
Albemarle Pippin	28	−0.9	Down	144
Duchess	57	−1.0	Down	67
Red Astrachan	61	−1.0	Down	80
Gravenstein	61	−1.2	Down	76
Wolf River	29	−1.3	Down	80
Russet	49	−1.5	Unknown	—
Gano	39	−1.8	Down	87
Winter Banana	20	−2.6	Down	86
Uncertain price trend				
McIntosh	36	—	None	125
Cortland	9	—	None	100

Table continued

[7] M. D. Woodin, *Cornell Univ. Agr. Expt. Sta. Bull.* 761, 1941.

TABLE 3 (*continued*)

Williams Red	13	—	None	92
Opalescent	12	—	Up	87
Starr	13	—	None	101
Golden Delicious	12	—	Down	162

[a] Prices (cents per bushel) are wholesale prices for eastern-grown apples. Wholesale prices are more than growers' prices but less than the prices paid by consumers. Factors that affect wholesale prices affect growers' prices also.

[b] Prices for each variety were compared with the average price of six important varieties (Baldwin, Ben Davis, McIntosh, Northern Spy, Rhode Island Greening, and Wealthy).

Vigor of Tree. Some varieties like Baldwin are vigorously growing trees and others like Delicious are not as vigorous.

Annual Bearing. Some varieties bear crops every year like the McIntosh and others like Wealthy will bear crops only every other year unless the blossoms are thinned in the spring of the "on year."

Fruit Drop. Some varieties like McIntosh drop their fruits prematurely. This difficulty can now be overcome in large measure by the use of naphthalene acetic acid sprays in the preharvest period.

Evenness of Fruit Ripening. In some varieties the fruits ripen very evenly throughout the tree but in others fruits must be harvested several times.

Insect and Disease Resistance. Some varieties like McIntosh are fairly resistant to red mite while others like Delicious are very susceptible. McIntosh is very susceptible to the scab disease and yet Rhode Island Greening is rather resistant. This same variation in resistance applies to other insects and diseases among the apple varieties.

Pollination Requirements. Some varieties like McIntosh are self-unfruitful and must be cross pollinated whereas others like Baldwin need very little cross pollination. Some varieties like Delicious have very good pollen and are excellent cross pollinators of unfruitful varieties. Others like Rhode Island Greening have poor pollen and are no good as a source of pollen for cross pollination.

Winter Injury. Some varieties are very much more susceptible to low winter temperatures than others. For example, the winter of 1933–34 wiped out many Baldwin trees in New York and New England. Up till that time Baldwin had been the leading variety. After that time McIntosh which is more winter hardy became the leading variety in the area.

There are other tree factors which determine the desirability of a given variety such as date of flowering in the spring and age at which the tree starts to flower.

B. Fruit Characteristics

Among the important fruit characteristics are the following considerations.

TABLE 4. FRUIT CHARACTERISTICS OF LEADING APPLE VARIETIES[6]

Variety	Approx. days after full bloom to picking maturity	Size of fruit	Color of fruit	Shape of fruit	Texture of flesh	Degree of acidity	Cold-storage season	
							Normal days[a]	Maximum days[b]
Delicious	140–150	Medium to large	Medium red (blush to 100%)	Oblong conic	Crisp, juicy, mealy when overripe	Low	90–120	180
Winesap	160–170	Medium to below medium	Dark uniform red	Conical	Hard, crisp, juicy	Medium	150–210	240
Jonathan	140–145	Medium to below medium	Uniform bright red	Round to round conic	Tender, crisp, juicy	Medium to high	60– 90	120
Baldwin	140–150	Medium to large	Medium red (blush to 100%)	Round to round conic	Hard, crisp, juicy	Medium	120–150	180–200
Stayman Winesap	160–165	Medium to large	Medium red (blush to 100%)	Roundish conic	Firm, crisp, juicy	Medium	120 150	150–180
Ben Davis	150–155	Medium to large	Striped, medium red	Round conic to oblong conic	Hard, dry, tough	Medium	120–150	240
Rome Beauty	160–165	Large	Medium red (blush)	Round to oblate	Firm, crisp to mealy when overripe	Medium to below medium	120–150	180–210
York Imperial	155–165	Medium to large	Light red (blush to 100%)	Oblate, oblique	Hard, crisp	Medium	120–150	150–180
McIntosh	125–130	Medium	Medium red (blush to 100%)	Roundish oblate	Tender, juicy	Medium	60– 90	120–150
Grimes Golden	140–145	Medium to below medium	Yellow	Roundish oblong	Medium tender, crisp, juicy	Medium	60– 90	120
Yellow Newtown	160–165	Medium	Yellow	Roundish oblate, sometimes oblique	Hard, crisp, juicy	Medium to above medium	150–180	240

Variety	Approx. days after full bloom to picking maturity	Size of fruit	Color of fruit	Shape of fruit	Texture of flesh	Degree of acidity	Cold storage season	
							Normal days[a]	Maximum days[b]
Wealthy	120–125	Medium	Medium red (blush to 100%)	Roundish oblate	Tender, crisp, juicy	Medium to high	0– 30	90
Yellow Transparent	70– 75	Small to medium	Yellow	Conic	Medium tender, juicy	Very high	0	90
R. I. Greening	135–145	Medium to large	Green yellow	Roundish oblate	Firm, fine grained, juicy	Medium to high	90–120	180
Northern Spy	145–155	Large	Bright striped red	Roundish conical	Firm, fine grained, tender, juicy	Medium	120–150	180
Gravenstein	110 115	Medium	Striped bright red (blush to 100%)	Oblate, angular	Firm, crisp, juicy	Medium to high	0– 30	90
Oldenburg (Duchess)	90– 95	Medium	Striped medium red (blush to 100%)	Roundish oblate	Firm, juicy, rather coarse	High	0– 30	90
Arkansas (Black Twig)	165–170	Medium to large	Medium dull red (blush to 75%)	Roundish oblate	Hard, crisp, coarse, juicy	Medium	120–150	180
Golden Delicious	140–145	Medium to large	Yellow	Conic	Firm, crisp, tender	Medium	90–120	150
Esopus Spitzenburg	145–150	Medium to large	Uniform bright red	Oblong conic	Firm, crisp, tender	Medium to high	90–120	180
Wagener	135–145	Medium	Bright red (blush)	Oblate, irregular	Firm, crisp, juicy	Medium	90–120	120–150
Stark	140–150	Medium to above medium	Medium to dull striped red	Roundish conic	Firm, crisp, coarse	Medium	120–150	180
Winter Banana	120–125	Medium to large	Yellow, red blush	Roundish conic	Firm, tender, rather coarse	Medium to low	90–120	150
Cortland	125–130	Medium to above medium	Medium red	Oblate	Tender, moderately juicy	Medium	90 120	150

[a] Represents the time that most of the fruit may be safely held.
[b] Represents the maximum period for safe holding of fruit picked, handled, and stored under the best conditions.

TABLE 5. Favorable Personal Opinion Ratings of Qualities of Baked Apples[a] (13 varieties, 1930 to 1935)

Variety	Av. no. of opinions for each quality	Acidity	Flavor	Texture	Melti-ness	Juiciness	Fineness	Appear-ance	Shape
	Favorable Ratings of Qualities, October to January, %								
1. Baldwin	41	57	61	37	25	45	26	48	43
2. Cortland	36	21	50	64	29	55	68	83	50
3. Fameuse	43	6	36	59	47	62	71	68	68
4. Golden Delicious	23	12	80	47	25	56	24	52	88
5. Jonathan	34	56	76	71	55	97	75	77	51
6. McIntosh	54	29	48	57	69	74	70	39	59
7. Northern Spy	51	64	50	65	45	78	33	50	36
8. Red Canada	21	9	35	26	8	65	48	39	65
9. R. I. Greening	60	41	19	22	12	13	39	16	64
10. Rome Beauty	60	5	23	20	10	15	32	58	66
11. Twenty Ounce	42	32	39	59	24	60	60	55	59
12. Wealthy	36	49	51	81	60	100	75	79	61
13. Winter Banana	35	15	55	44	18	51	39	68	87
All varieties	41	32	45	49	34	56	51	54	60

Variety	Av. no. of opinions for each quality	Acidity	Flavor	Texture	Melti-ness	Juiciness	Fineness	Appear-ance	Shape
	Favorable Ratings of Qualities, February to April, %								
1. Baldwin	26	35	—	15	17	23	69	8	81
2. Cortland	37	24	11	37	42	29	84	69	82
3. Fameuse	15	—	8	25	20	19	75	63	75
4. Golden Delicious	25	—	9	12	28	16	44	8	92
5. Jonathan	16	24	73	47	15	76	41	41	47
6. McIntosh	26	15	16	42	27	46	81	31	100
7. Northern Spy	25	36	20	44	22	48	56	56	40
8. Red Canada	19	—	7	15	—	30	20	10	60
9. R. I. Greening	21	43	—	24	14	10	48	—	56
10. Rome Beauty	37	—	3	—	11	—	43	46	90
11. Twenty Ounce	10	36	—	—	11	40	45	—	100
12. Wealthy	21	52	19	48	32	62	71	43	62
13. Winter Banana	16	—	25	18	7	12	29	12	46
All varieties	23	20	13	25	21	29	57	33	73

[a] M. C. Pfund. *Cornell Univ. Agr. Expt. Sta. Mem.*, 225, 1939.

TABLE 6. Favorable Personal Opinion Ratings of Qualities of Applesauces[a] (13 Varieties, 1930 to 1935)

Variety	Av. no. of opinions for each quality	Acidity	Flavor	Texture	Melti-ness	Juiciness	Fineness	Appear-ance	Consis-tency
	Favorable Ratings of Qualities, October to January, %								
1. Baldwin	52	62	45	16	7	26	46	41	26
2. Cortland	42	24	56	61	43	80	47	14	82
3. Fameuse	48	6	8	41	67	84	41	—	85
4. Golden Delicious	25	19	45	27	36	50	40	62	68
5. Jonathan	36	55	65	45	47	65	47	85	54
6. McIntosh	60	31	44	76	81	100	66	6	51
7. Northern Spy	56	52	57	43	33	78	31	60	70
8. Red Canada	25	26	28	29	13	46	25	43	67
9. R. I. Greening	65	31	23	15	10	13	29	39	43
10. Rome Beauty	56	2	10	12	4	27	44	47	58
11. Twenty Ounce	47	48	31	54	33	73	38	67	76
12. Wealthy	37	50	50	73	73	88	59	67	72
13. Winter Banana	34	21	42	13	—	46	36	54	70
All varieties	45	34	38	39	35	58	42	43	62

Variety	Av. no. of opinions for each quality	Acidity	Flavor	Texture	Melti-ness	Juiciness	Fineness	Appear-ance	Consis-tency
	Favorable Ratings of Qualities, February to April, %								
1. Baldwin	33	21	19	9	13	30	43	38	64
2. Cortland	41	11	30	70	51	77	71	25	89
3. Fameuse	16	—	8	6	17	47	12	—	100
4. Golden Delicious	31	—	17	16	19	23	42	45	52
5. Jonathan	15	25	29	56	25	75	31	65	100
6. McIntosh	28	14	35	38	48	79	61	7	82
7. Northern Spy	26	38	15	38	29	68	27	44	92
8. Red Canada	18	—	—	5	—	21	53	—	25
9. R. I. Greening	24	42	8	21	13	38	21	50	71
10. Rome Beauty	36	—	—	8	6	22	47	14	64
11. Twenty Ounce	11	36	9	18	44	91	—	45	85
12. Wealthy	24	29	21	63	64	92	59	42	58
13. Winter Banana	15	—	18	13	—	38	31	56	92
All varieties	25	16	17	30	27	52	43	32	74

[a] M. C. Pfund, *Cornell Univ. Agr. Sta Mem.*, 225, 1939.

TABLE 7. DESIRABILITY OF VARIOUS APPLE VARIETIES FOR DIFFERENT PURPOSES

Variety	Dessert	Sauce	Baking	Freezing	Juice[a]	Dehydration	Canning
Arkansas Black	Fair	Good	Fair	—	—	—	—
Baldwin	Poor	Good to excellent	Good	Excellent	Good to very good	Excellent	Good to very good
Ben Davis	Very poor to poor	Fair	Poor to fair	—	Poor to fair	Excellent	Fair to good
Cortland	Very good to excellent	Fair to good	Poor to good	Very good	—	—	—
Delicious	Excellent	Fair	Good	Fair	Fair to very good	Poor	Poor to good
Esopus Spitzenburg	Good	Good	Fair	Very good	Good to very good	Excellent	Good to very good
Golden Delicious	Excellent	Poor	Poor	Very good	Poor to fair	Fair	Fair
Gravenstein	Good	Good	Poor	Good	Fair	—	—
R. I. Greening	Poor	Excellent	Fair	Excellent	Good	Good	Good
Grimes Golden	Excellent	Good	Poor	Very good	Fair to good	Good	Very good
Jonathan	Very good to excellent	Fair to good	Poor	Very good	Good	Good	Good
McIntosh	Excellent	Poor to fair	Poor to fair	Good	Good to fair	—	Fair
Northern Spy	Excellent	Fair	Very good	Excellent	Good to very good	Excellent	Good
Oldenburg	Poor	Good	Poor	—	—	—	—
Rome Beauty	Fair	Good	Excellent	Fair to very good	Fair to good	Good	Good
Stark	Fair	Poor to fair	Good	Very good	Fair	—	—
Stayman Winesap	Excellent	Good	Good	Good	Good	Good	—
Wealthy	Fair to good	Very good to excellent	Poor to good	—	Good	—	Very good
Winesap	Very good to excellent	Fair to good	Poor	Very good	Good to very good	Good	Good
Winter Banana	Good	Fair	Poor	—	Good	—	—
Yellow Newtown	Poor	Good	Fair	Good to excellent	Good	Good	Good to very good
Yellow Transparent	Poor	Good	Poor	—	Fair	—	—
York Imperial	Fair	Good	—	—	—	—	—

[a] The best apple juice is often made from blends of several varieties. Blending is often practiced also with applesauces for best quality (See Chapters XII–XV).

Price. A given variety may have many good tree characteristics and yet have fruit which is relatively unsalable. A fruit grower must have fruit which brings a relatively high price per bushel if he is going to make profits through the years. One of the difficulties in this connection is that he often cannot predict 15 years ahead what the price situation will be for a given variety that he contemplates planting, and it takes 15 years or more for an apple tree to get into good commercial production. Table 3 does indicate the average price of some apple varieties on the New York market and what the price trend has been.

Size and Shape. While fruit size may vary considerably with the leaf–fruit ratio as the fruit matures on the tree, some varieties have characteristically large fruit (Wolf River) and some varieties have characteristically small fruit (Yellow Transparent). Fruits of different varieties vary considerably in shape. They may be round, oblate, conical, oval, ovate (viewed at right angles to axis), or they may be regular, compressed, or ribbed (viewed along axis). Variations in shape and size of some common varieties may be seen in Table 4.

Color. Some apples may be wholly red or only partially red. Sometimes the red is striped and sometimes it occurs as a "blush" on the cheeks of the fruit. Shades of the red also vary from variety to variety. Some varieties may be wholly green or yellow. Typical color of some common varieties is given in Table 4.

Flesh Texture. The texture of the flesh of a given apple variety may be fine, medium, coarse, tough, tender, buttery, firm, mealy, crisp, juicy, or dry. Of course, texture may vary within a given variety with maturity of the fruit.

Dessert Quality. Apples vary widely in their dessert quality. Some of the factors which determine dessert quality are discussed on pp. 170–175. Estimation of dessert quality is obviously a personal opinion or appraisal. For example, Rhode Island Greening is not commonly considered a dessert apple yet there are people who consider it of higher eating quality than Delicious. The dessert quality of some common varieties is listed in Table 7. Dessert quality also varies with maturity. Another factor which may cause differences in the estimate of the eating quality of a given variety is the location in which it is grown. For example, Yellow Newtowns grown in California have somewhat different eating quality from those grown in Virginia or New York.

Cooking Quality. For good cooking quality apples usually must have a rather high acid content. Most people prefer varieties for cooking that are firm textured and do not "fall apart" when cooked. On the other hand, while McIntosh is a soft-fleshed variety and is ordinarily not considered an applesauce fruit, many people prefer sauce made from this variety especially before it becomes overripe. For canned applesauce it is more essential that the variety have a firm-textured flesh and not "mush up" when cooked in the can. For baking purposes it is also rather essential that the fruit "hang together" during the baking process and this demands a firm-textured fruit like Rome Beauty or Northern Spy.

The comparative cooking quality of different common varieties is listed in Tables 5, 6, and 7. There are some discrepancies in the rating of different varieties as to cooking quality in Tables 5 and 6. This emphasizes the personal

TABLE 8. Susceptibility of Apple Varieties to Physiological Disorders

Variety	Water core	Scald	Soft scald	Bitter pit	Miscellaneous
Delicious	Severe	Slight	None	Slight	Mealy breakdown
Winesap	Medium	Medium	None	None	
Jonathan	Medium	Slight	Severe	Slight	Jonathan Spot
Baldwin	Slight	Medium	None	Severe	
Stayman	Medium	Severe	None	Medium	Internal breakdown, cracking
Ben Davis	Slight	Medium	—	Slight	
Rome Beauty	Slight	Medium	Medium	Slight	
York Imperial	Slight	Severe	None	Severe	
McIntosh	None	Slight	None	Slight	Brown core
Grimes Golden	Medium	Severe	Severe	Medium	Shriveling
Yellow Newtown	Slight	Medium	None	Slight	Internal browning
Wealthy	Slight	Medium	Medium	Slight	
Transparent	Medium	None	None	None	
R. I. Greening	Slight	Severe	None	Severe	Mealy breakdown
Northern Spy	Slight	Slight	None	Severe	Spy spot, breakdown
Gravenstein	Slight	Slight	None	Severe	
Oldenburg	Slight	Slight	None	None	
Arkansas	Medium	Severe	None	Slight	
Golden Delicious	Slight	Slight	Severe	None	Shriveling
Spitzenburg	Slight	Slight	None	Slight	
Wagener	Slight	Severe	None	Slight	
Stark	Slight	Medium	None	Slight	
Winter Banana	Slight	Slight	Severe	Slight	
Cortland	Slight	Medium	Slight	Slight	

appraisal factor of different groups of judges. Cooking quality usually diminishes as the fruits ripen in storage (see Table 5).

Storage Life. Varieties of apples differ widely in their length of storage life. Some apples like Yellow Transparent respire very rapidly and have a very short storage life whereas others like Yellow Newtown have a very long storage life. Differences in length of storage life among the common varieties appear in Table 4.

Storage Disorders. Some apples like McIntosh are quite resistant to storage disorders like bitter pit while others such as Northern Spy are very susceptible. Differences in susceptibilty to storage disorders may be seen in Table 8.

CHAPTER III

DEVELOPMENT AND STRUCTURE OF THE APPLE FRUIT

A. Introduction

Some knowledge of the developmental morphology and anatomy of the apple fruit seems well justified. What do you eat when you eat an apple? Truly enough the apple fruit develops from the flower—but one should know what particular flower parts have become fleshy and edible. Some flower parts disappear during the development of the fruit, others remain as remnants on the mature fruit and still others may become tough and fibrous.

Some tissues or fruit parts are of more interest to the fruit technologist than others. Adaptability of a given variety to a particular technological purpose depends not only upon its chemistry but also upon its morphology and anatomy. For example, it has been found that the cooking quality of apples to be used for applesauce varied inversely with the proportion of carpel wall and vascular tissue present. The same study also found that sauce cooking quality varied directly with cell size and inversely with cell cohesion.[8]

In the proper interpretation of physiological functions like transpiration and respiration it would seem well to know what role the cuticle, lenticels, and other fruit parts play. For example, Golden Delicious shrivels more during storage than many other varieties because of its cuticle structure.[9] Certain physiological disorders like bitter pit influence certain anatomical parts of the fruit more than they do others.

[8] A. B. Milam and H. B. Gardner, *Oregon Agr. Expt. Sta. Bull.*, 124, 1915.
[9] A. Meyer, *Proc. Am. Soc. Hort. Sci., 45*, 105 (1944).

B. Development of Fruit from Flower

What is a fruit? By botanical definition a fruit is a mature or ripened ovary or ovaries together with any closely associated parts. Some fruits like peaches and plums involve only the ripened ovary of a single carpel (made up of stigma, style, and ovary). Other fruits develop from more than one carpel (*i.e.,* grape). In the fruits that

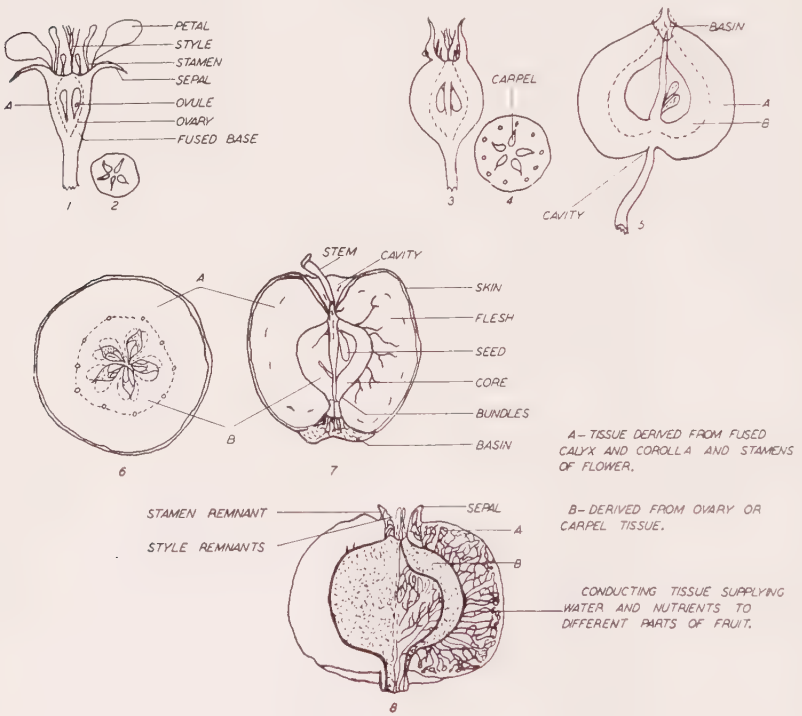


Fig. 1. Development of the apple fruit from the flower stage.[12]

have been named thus far only the mature ovary is involved in the fruit. In the pome fruits (apple, pear, and quince) more than just the ovaries are involved. The five ovaries of the apple flower are imbedded in tissue which surrounds them. In the pome fruits this surrounding tissue as well as some of the ovary or carpel tissue becomes fleshy and edible.

According to this botanical definition some fruits may be wholly inedible. The horse chestnut would be in this category. Pomology has "inherited" only those fruits which are not only edible but those which grow on perennial plants.

The Apple Flower. In order really to appreciate the fact that the apple fruit does develop from a flower, the structure of an apple flower is presented in Figure 1. Since the diagram of the apple flower in this figure is a longitudinal section, it cannot show all of the flower parts. For example, only two sepals are shown whereas actually there are five. On the typical apple flower there are usually five petals (the corolla), five sepals (the calyx), five carpels (each carpel being made up of stigma, style, and ovary) and approximately 20 stamens. In each ovary there are usually two ovules although this number may vary. For example, in Northern Spy there may often be as many as four or five ovules per carpel or ovary (resulting in 20 or more seeds per fruit).

It should be especially noted in Figure 1 that the ovaries are encased in tissue which grows up around them and yet is attached to them. This outer structure is interpreted by one school of anatomists[10,11] as being "receptacle" and by another as being the fused base of the calyx (sepals), corolla (petals), and stamens.[12] In this book the latter interpretation will be used.

Steps in Fruit Development. Fruit development in most apple varieties requires both pollination and fertilization. A few varieties (most notably Baldwin) will set a fair crop of fruit without very much fertilization or with very few seeds. Pollination is described as the transfer of pollen from the anther (where it is formed) to the stigma (at the distal end of the style). If the pollen of a given variety is transferred to the stigma of a flower of the same variety it is said to be "self pollination." When the pollen is from another variety it is called "cross pollination." Cross pollination is required in most varieties of apples to get a good fruit set. The pollen germinates on the stigmatic surface of the style and sends a pollen tube down the style of the flower. Included in this pollen tube are the sperms or male sexual nuclei. The pollen tube extends into the carpel cavity containing the ovule. In the basal portion of the ovule is the egg or the female sexual

[10] E. J. Kraus, *Oregon Agr. Expt. Sta. Bull.*, 1, p. 1, 1913.
[11] H. B. Tukey and J. O. Young, *Botan. Gaz.*, 3, 1942.
[12] L. H. MacDaniels, *Cornell Univ. Agr. Expt. Sta. Mem.*, 230, 1940.

cell. The sperm and the egg unite—resulting in fertilization. This fertilized egg grows into the embryo within the expanding and growing ovule. The surrounding endosperm constitutes the food of the embryo when the embryo is permitted to grow (*i.e.*, as a growing seedling). The embryo and the endosperm with their enclosing seed-coats constitute the *seed*.

The question is raised here as to why seed production is discussed when the pomologists and technologists are seldom interested in the seed but rather in the edible portion of the fruit. The reason is that most apple varieties require seed production for fruit production. While there are some seedless varieties (Wilson's Seedless) and some varieties which may approach seedlessness when not cross pollinated (Baldwin), most varieties must have from three to five seeds as a minimum number for fruits to develop. There is some indirect evidence to indicate that seed formation seems to stimulate the production of a hormone or hormone-like substance which induces fruit formation. A full complement of seeds is needed not only for fruit setting but for well-shaped fruits in most varieties. For example, when a McIntosh fruit has four seeds (out of a possible ten) and they are located in adjoining carpels, the fruit is larger on that side than on the seedless side. In summary, even though the seeds are not important in fruit technology their formation is necessary for the stimulation in development of the edible portion of the fruit.

A mature apple tree may have as many as 100,000 flowers at the time of full bloom. If all of these flowers were to set fruit, and if all of them developed into full-sized fruits, there would be around 800 bushels of fruit on each tree. Obviously a single tree could not support that many bushels of apples. A single tree could not support the weight of so much fruit let alone supply all the water and necessary foods. A good yield for such a tree would be 30 bushels of fruit. Such a yield could be had with only 4 or 5% of the flowers setting. A fair yield of 15 bushels of fruit could be had with only 2% of the flowers setting. Hence, it may be seen that a set of only 2 to 4% of the flowers is needed to get a commercial crop of apples.

From the commercial standpoint the problem is how to get even 2 to 4% of the flowers to set. Whether or not the flowers set and in what numbers depends upon pollination, fertilization, food supply, water supply, and freedom from frost, insects, and diseases. If too many flowers set (*i.e.*, 10% or more) the fruits will tend to be small

unless they are thinned off during the summer to the proper leaf–fruit ratio. There is a heavy drop of flowers after full bloom because of lack of pollination, lack of fertilization, or some other cause. There is a second drop of young fruits in early July when the small fruits drop off in large numbers. This drop is called the "June drop."

Development of Carpels. Figure 1 indicates the relative growth of the carpels in the developing fruit. The inner part of the carpel or ovary wall becomes leathery and tough and in the mature fruit constitutes the inedible part of the core. The middle and outer part of the ovary wall extends out to the ring of main vascular bundles (Fig. 1) and constitutes a part of the edible portion of the fruit. The tough cartilaginous portion of the carpel develops rapidly for two to four weeks after full bloom in McIntosh reaching maximum size in transverse diameter the earliest of any of the fruit tissues. The fleshy and outer portion of the carpels continues growth approximately two weeks longer.[11]

Development of Edible Part of Fruit. The outer layer of cells on the developing young fruit is the *epidermis.* While variations may occur in its development among varieties, typical development as studied in McIntosh will be outlined.[11] About the time of full bloom, the epidermal cells were still dividing and were thin walled and full of protoplasm. The cells were somewhat elongated (having started as small, isodiametric cells) and divided by radial walls. Within a couple of weeks the cells were somewhat broader but the radial measurement was still broader than the tangential. The cytoplasm was becoming vacuolated. No more cell division was noted at this time although the cells were still alive. After another month the cells had broadened and flattened so that the tangential measurement was greater than the radial. The cells seemed to lengthen tangentially as the fruit enlarged. After still another month the cells started to separate and the spaces between them were filled with *cuticle.*[13] The cell contents were disorganizing by this time. By harvest time the epidermal cells were either flattened or crushed. Many of them were completely separated from adjacent cells by the cuticle and some were even surrounded by this cuticle. The cell contents were completely disintegrated by this time and it is doubtful if the cells were alive.[11,13]

The *cuticle* was continuous and about 1.4 mμ thick at the time of full bloom. Within two weeks after bloom the cuticle was about 5

[13] H. P. Bell, *Can. J. Research, 15,* 391 (1937)

mμ thick and completely filled the bases of the epidermal hairs. It was continuous except over the stomata or young lenticels where it shaded off to nothing. After another month of growth the cuticle was 11 mμ thick and fairly uniform in thickness. After still another month of development on the tree the cuticle was 16 mμ thick and was starting to extend between the epidermal cells. By harvest time, the average thickness of the cuticle on McIntosh was 23 mμ and extended between the epidermal cells to the hypodermis and even under the epidermal cells (see Fig. 2).

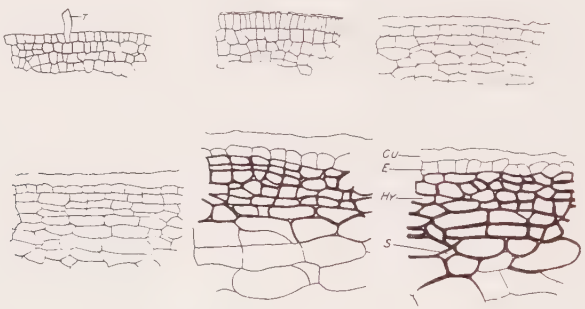


Fig. 2. Cellular changes in the epidermis and hypodermal layers for McIntosh apples: top left, one month before full bloom; top middle, full bloom stage; top right, one month after full bloom; lower left, two months after full bloom; lower middle, three months after full bloom; lower right, four months after full bloom. *T,* trichome or hair; *Cu,* cuticle; *E,* epidermis; *Hy,* hypodermal layer; *S,* intercellular space.[11]

On the surface of the epidermis there were epidermal *hairs* when the flower was at the stage of full bloom. Early in their life the hairs were part of the epidermal cells from which they extended. Within a couple of weeks after full bloom the hairs were dead and their bases were filled with cuticle. After another month the hairs were gone except in and around the depressions of the calyx and stem ends of the fruit. By harvest time all the hairs were gone.[13]

As the young fruit developed on the tree, openings in the skin called *lenticels* appeared.[14,15] These lenticels may have arisen from stomata which stopped functioning as stomata early in the develop-

[14] H. F. Clements, *Botan. Gaz., 97,* 101 (1935).
[15] A. Zschokke, *Landw. Jahrb. Schweiz., 11,* 153 (1897).

ment of the fruit. They may also have arisen from breaks in the epidermis caused by a complete removal of the epidermal hairs. A third possibility is that they might have developed from other epidermal breaks brought about by the inability of the epidermis to keep pace with the expanding inner tissues of hypodermis and parenchyma during growth. During their development they usually became closed through a cutinization or suberization process, thus preventing free passage of gases from the inner tissues to the outside air. In some cases, however, the lenticels may not have become closed or even partially closed.

The *hypodermis* consisted of several layers of cells just beneath the epidermis. At the time of full bloom there were about four layers of hypodermal cells in McIntosh. In some varieties of apples it has been found that when there was deep red coloration on the fruit there was a hypodermal layer 8–10 cells deep on the red side and only 6 deep on the uncolored side.[16] By the time the fruit was half grown the regular arrangement of cells was lost in the hypodermis and the cells were filled with a heavy granular deposit.[13] By harvest time the hypodermis was a dense mass of closely packed, thick-walled, tangentially elongated, and radially flattened or crushed cells. In some varieties of apples a *periderm* is formed which is capable of forming new "corky" cells.[17] Periderm development is very likely to develop within the hypodermis when there is an injury to the skin such as that resulting from adverse weather or spray damage. *Russetting* of some fruits seems to result from the development of this periderm. This periderm tissue is a cork cambium and is capable of forming corklike cells which result in the russetted appearance of some fruits. When the epidermis is injured or killed by low temperatures (frost) and by toxic spray materials like lime sulfur, there is likely to be a formation of this russet. As a result of frost damage when the fruits are just forming in the spring, there may be a conspicuous ring of russet. This is called a "frost ring." Severely russetted fruits are very subject to rapid transpiration or water loss.[17a]

The *parenchyma of the fused bases of the calyx, corolla, and stamens* constitutes the major portion of the edible portion of the mature fruit. Cell division within this tissue (just under the hypodermis

[16] J. R. Magness and H. C. Diehl, *J. Agr. Research, 27* (1924).
[17] H. P. Bell, *Can. J. Research, 15,* 560 (1937).
[17a] C. E. Baker, *Proc. Am. Soc. Hort. Sci., 27,* 75 (1930).

extending down to the carpel region) seems to be completed within three weeks after full bloom with McIntosh in New York.[11] Studies with other varieties of apples in other places have shown little or no cell division within this tissue after the middle of June.

This means that further growth and increase in size of this region is due to cell enlargement and increase in size of the *intercellular spaces*. As has been stated previously some workers interpret this tissue as being *cortex*, instead of as parenchyma of the floral tube (fused base of sepals, petals, and stamens).

The outer carpel region (see Fig. 1) seems to show considerable cell division for a short period (*i.e.*, 10–11 days) in McIntosh after full bloom. After this time further development in size is due to cell enlargement and to increase in size of the intercellular spaces. This tissue is called *pith* by those workers who interpret the edible portion of the apple as being stemlike instead of being floral in basic origin.

C. Anatomy of Mature Fruit

The *epidermis* of the mature fruit has already been described as somewhat flattened or crushed cells (one layer deep). The cell contents are completely disintegrated and so are apparently dead.[13] The *cuticle* on mature fruits varies considerably in thickness and in nature chemically from variety to variety. It has often been assumed that the reason Golden Delicious apples shrivelled so badly was because they had a thin cuticle. Actual study[9] has shown that this is not true. This variety has a thicker cuticle than that of Winesap, a variety which does not shrivel badly. The cuticle of Winesap was found to be of a more oily nature, however, than that of Golden Delicious. A more logical explanation for the more rapid transpiration (water vapor loss) of Golden Delicious seems to be the fact that there are large breaks in the cuticle (see Fig. 3), whereas in Winesap the cuticle is more or less continuous. There may be rather "large" (nevertheless, microscopic in size) cracks. These cracks in this variety result in exposed epidermis and hypodermal cells unprotected by either cuticle or cork. At least one other study has shown that transpiration rate could not be associated with cuticle thickness.[18] Figure 2 shows the cuticle on McIntosh. Brushing and wiping for removal of spray residue does not seem to remove very much if any cuticle. The cuticle may continue to develop in thickness after harvest.

[18] S. A. Pieniazek, A Study of Factors Influencing the Rate of Transpiration of Apple Fruits. Thesis, Cornell Univ., 1942.

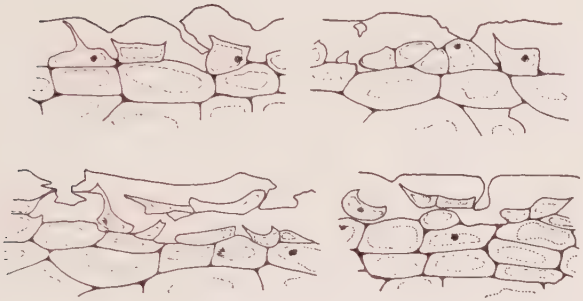


Fig. 3. Typical breaks, cracks, "tubes," and exposed cells in the skin of mature Golden Delicious apples.[9]

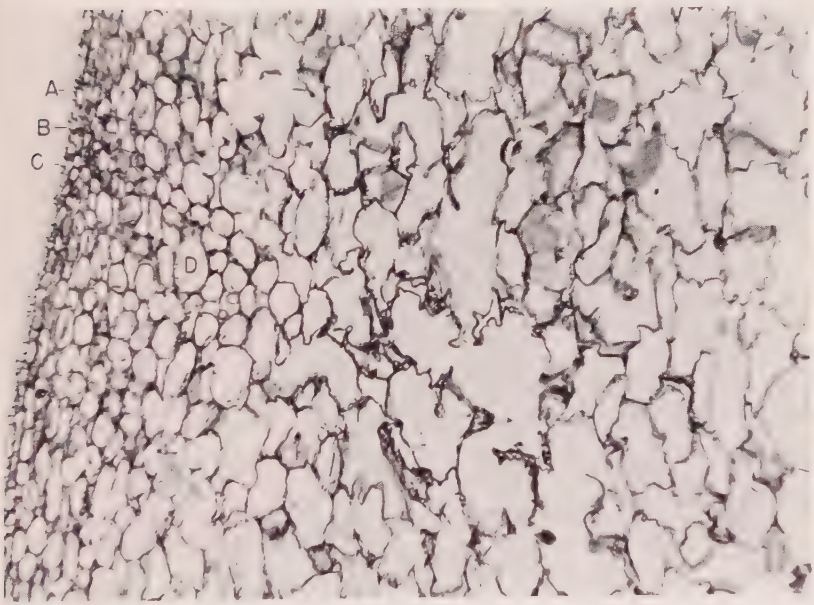


Fig. 4. Cross section of outer portion of a Northern Spy apple: *A,* cuticle; *B,* epidermis; *C,* hypodermis; *D,* parenchyma cells. The round globules around some of the cell walls are starch grains. Some of the parenchyma cells are torn and some of the cells are collapsed. This condition is one of the first indications of bitter pit or stippin in apples.

On the surface of some apple varieties there is a "bloom." This is a powdery material that seems to be secreted from the cuticle. It is not an integral part of the cuticle. The bloom may be readily wiped off, but may be regenerated on apples even after picking.

Lenticels in the mature fruit vary in number from 450 to 800 in a variety like Winesap to 1500 to 2500 per fruit in Spitzenburg.[14] These lenticels may be open or closed.

The *parenchyma of the floral tube* (*i.e.,* fused base of sepals, petals, and stamens) comprises the major portion of the edible part of the mature fruit. The size of these cells varies tremendously with varieties. It may even be that growing conditions influence cell size within a given variety. Baldwin and Northern Spy are among varieties that have large parenchyma cells. See Figure 4. Delicious has medium-sized cells. Winter Banana, Grimes Golden, and Rome Beauty have small cells within the floral tube. In a study of 16 varieties it was found with an exception of three varieties that respiration rate was inversely proportional to cell size in the parenchyma of the floral tube.[19]

A conspicuous and important feature of the floral tube parenchyma of any apple variety is the *air spaces.*[19] It has been estimated that 25% of the volume of the parenchyma is composed of intercellular spaces between the cells. This large amount of air space may account for ready diffusion of gases from one part of the fruit to another. For example, it has been found that water may move in the vapor form from the warm side of an apple to the cold side, presumably through these interlacing air spaces.[20]

Just inside the main vascular bundles[12] which form the *core line* of an apple fruit is the *parenchyma region of the carpels.* If the edible portion of the apple is interpreted as being receptacle in nature, this tissue is properly called pith, because stem structure (receptacle) interpretation demands it. If the edible portion is interpreted as being the fused bases of sepals, petals, and stamens, this portion must be called part of the ovaries or carpels.

Just inside the outer ovary wall, but not yet discernible from it without special clearing solutions, is the *middle* and *inner ovary wall* (Fig. 1). This tissue contributes only a small portion of the edible part

[19] W. H. Smith, *Rept. Food Investigation Board, 1936,* 137 (1937).
[20] O. F. Curtis, *Am. J. Botany, 24,* 705 (1937).

of the fruit. The leathery inner carpel wall forms what is commonly called the *core lining* of the seed cavities.

Of course, in most apple varieties there are seeds within the five individual carpels. These have developed from the ovules of the flower as a result of fertilization.

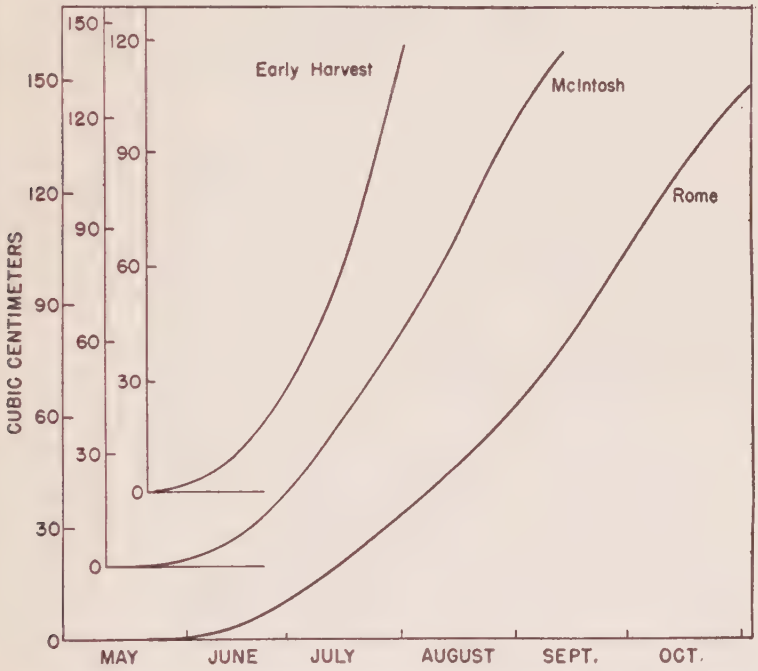


Fig. 5. Increase in the volume of fruits of Early Harvest, McIntosh, and Rome Beauty apples from full bloom to maturity.[22]

Remaining on the mature fruit are the sepals at the apex of the fruit. Sometimes these sepals close completely over the cavity and in other varieties they do not. If they remain more or less upright it leaves a more or less open passage down through to the seed cavities. In Gravenstein it has been found that the bases of these sepals (the calyx) are structurally very weak and may result in a very open entrance to the seed cavities. Moldy core in this variety is attributed to this cause.[21]

[21] H. P. Bell, *Can. J. Research, 18,* 69 (1940).

Remnants of the stamens and styles may also be found at the apex of the apple. In fact, all of the original flower parts except for the petals persist in developed or remnant form on the mature fruit.

Growth Curve of Apple Fruit. Actual growth of the various tissues of the apple has been discussed in the foregoing paragraphs. The entire fruit increases in volume throughout the growing season in a fairly uniform fashion. The steepness of the growth curve depends of course upon the variety and the length of its growing season. The apple growth curve is a fairly straight line unlike that of the peach and other drupe fruits (see Fig. 5).[22]

The increase in fruit size in apples as they mature on the tree depends upon a number of environmental conditions. Among the more important *environmental* factors are: water supply, sunshine, temperature, and soil fertility. Among some of the important *tree* characteristics which determine size are leaf–fruit ratio, tree vigor, tree age, and variety.

[22] H. B. Tukey and J. O. Young, *Botan. Gaz., 104,* 3 (1942).

CHAPTER IV

SOME ENVIRONMENTAL AND CULTURAL FACTORS AFFECTING THE CHEMICAL COMPOSITION AND PHYSIOLOGY OF APPLES

The purpose of this chapter is merely to outline some of the common factors which may affect the composition and physiological behavior of the apple. It is not intended that a full discussion of all the environmental and cultural conditions affecting the apple will be dealt with. The details of all the environmental and cultural factors affecting growth, composition, and physiology of the apple should be obtained from a good text on pomology.[23-25] These are discussed briefly here merely to emphasize their importance to the food technologist or other person who is not primarily interested in pomology and may not be aware of their significance.

The exact way in which environmental or cultural factors may influence the composition or physiology of the apple is discussed in later sections. However, some examples will be given as to ways in which these factors may affect fruit physiology and composition in order to illustrate their significance.

A. Environmental Factors

Light. Light intensity, quality, and duration are important determinants of the rate of photosynthesis of apple tree leaves. Of course, photosynthesis provides the sugars which constitute such a

[23] J. H. Gourley and F. S. Howlett, *Modern Fruit Production.* Macmillan, New York, 1941.

[23a] N. F. Childers, *Fruit Science.* Lippincott, New York, 1949.

[24] E. C. Auchter and H. B. Knapp, *Orchard and Small Fruit Culture.* Wiley, New York, 1937.

[25] V. R. Gardner, F. C. Bradford, and H. D. Hooker, Jr., *The Fundamentals of Fruit Production.* McGraw-Hill, New York, 1922.

large part of the solids or soluble solids of apple fruits. These sugars are used as a source of energy in respiration while the fruit is on the tree and after harvest.

When a very cloudy growing season is experienced a profound effect may be noted on the chemical composition of the fruit, particularly the sugar and acid components. The physiology of the fruit after harvest may also be affected through an effect on processes like respiration. Physiological disorders like internal browning and brown core may be worse following such a growing season.

Light may also affect the coloration of apples, through its effect on the base materials involved in color formation. Red coloration of the fruits in the fall does not develop properly unless there is adequate light.

Water. There must be an adequate water supply in the orchard soil at all times during the growing season, otherwise the fruit does not grow to normal size. If water is a limiting factor photosynthesis is checked and fruit quality may thus be impaired. Red coloration of the fruit does not develop properly unless water is present in sufficient amounts during the latter part of the growing season. Of course, water is involved not only in fruit growth but in tree growth as well and, unless the latter is normal, crop size is materially affected.

In areas where rainfall is deficient during the growing season, irrigation is practiced. Irrigation is seldom necessary in the eastern or middle western growing sections of the United States but is commonly practiced in the Pacific Northwest.

Temperature. Temperature is of extreme importance at all seasons of the year in the growing of apples. *Winter* temperatures may be so low as to result in injury to the buds or the wood of the tree. On the other hand, if they are not low enough the "rest period" of the trees is not broken and the trees do not leaf out normally in the spring. It is for this reason that apples cannot be grown satisfactorily in the southern part of the United States.

Springtime temperatures may also be a critical factor. If the temperatures go down to 26 or 27°F. for an hour or more after the trees come into full bloom the flowers will be killed. This frost hazard to the flowers and young fruits constitutes one of the biggest problems of the fruit grower. The fruit grower tries to avoid it by selecting a frost-free site. This may be near a large body of water where the prevailing winds sweep from the water over the orchard. It may be

on a hillside where there is good air drainage. In some sections where the temperature is not likely to drop more than a few degrees below the killing temperature orchard heating is practiced. Spring temperatures may be so low that bees do not fly for pollination or so low that pollen will not grow down the style of the flower even though pollination has taken place.

Summer temperatures affect the rate of growth of the tree and the rate of photosynthesis of the leaves and hence may affect fruit quality. If summer temperatures are too high there may be actual heat injury to the fruit.

In the *fall* the ideal situation is to have warm days and very cool nights. The warm days make for maximum photosynthesis and hence the manufacture of sugars and the cool nights induce maximum formation of red coloration of the fruits. If the temperatures drop too low during the fall months there may be actual freezing injury to the fruit. High temperatures during the period just prior to harvest may induce excessive abscission (*i.e.,* dropping) in some varieties.

Other Climatic Factors. Another climatic factor is *wind.* If the wind hazard is too great there may be actual fruit losses due to excessive fruit dropping. *Hail* is a real source of danger. Hail may ruin the apples or may damage the fruit enough to impair the market value. It may also damage the leaves enough to reduce photosynthesis.

Soil. The prime prerequisite of an orchard soil is that it be well drained. It has been pointed out that water is essential for apple tree growth but excess water in the soil also results in poor tree growth. Although the trees may live for some little time on a poorly drained soil, they are usually not very long lived and are very unproductive. The soil should be well drained to a depth of from four to six feet if the trees are to grow normally.

When a soil has too much clay in it and hence is poorly drained, the excess water may not directly affect tree growth but the effect is an indirect one. When the soil interspaces are filled with water during a large part of the growing season, oxygen is excluded and the roots cannot respire and live normally. Hence the excess water effect is one of lessened *aeration* in the soil.

Fertility of the soil is of some importance in selecting an orchard site for apples but it is not as important as it might be for some field crops. If a soil is extremely sandy it is likely to be well drained but have low fertility. Trees grown on such a soil can be grown very

satisfactorily because the needed fertility can be added to the soil by means of chemical fertilizers. Of course, ideally, the soil should be well drained and yet fertile. Still one would look first for good drainage and take fertility also if that is possible.

The apple tree in its growth process requires a number of minerals besides nitrogen for its growth. Among these are phosphorus, magnesium, potassium, manganese, calcium, sulfur, iron, boron, copper, and zinc.

B. Cultural Factors

Soil Fertilization. Nitrogen is the element in the soil that is most likely to be lacking for normal apple tree growth and fruit production. It may be applied in a number of forms. Manure, sodium nitrate, ammonium sulfate, calcium cyanamide, urea, and ammonium nitrate are among the common forms used in making nitrogen applications to the apple orchard. Just how much nitrogen to use in fertilizing an apple tree is difficult to recommend. Although the rule "a quarter of a pound of nitrate of soda (or its equivalent) per year of age of the tree" has been used, it has definite limitations. For certain varieties in particular it is possible to add entirely too much nitrogen.

One should consider the purposes or benefits of nitrogen fertilization as well as its limitations before deciding how much to use per tree.

Objectives in using nitrogen fertilizer: (*a*) To improve tree vigor in order to get good annual growth of shoots and to get large, dark green leaves. (*b*) To improve fruit setting; nitrogen additions in early spring improve the set of fruit and hence increase yields.

Objections to using too much nitrogen fertilizer: (*a*) Excess of nitrogen in the soil in late summer may induce susceptibility to winter injury. (*b*) Excesses of nitrogen result in poor development of the anthocyanins in apples. (*c*) Excesses of nitrogen may result in increased development of certain physiological disorders in storage like bitter pit and brown core. (*d*) Too much nitrogen in some cases may result in increased living rate or respiration of the fruit; this will be discussed in detail later in the book. (*e*) Too much nitrogen in the soil during late summer induces excessive dropping of premature fruits.

The orchardist must try to strike a balance between the advantages and disadvantages of adding nitrogen. He may have to sacrifice the yield of a variety like McIntosh to get the proper color. He must remember that an orchard which is cultivated may not need as much

nitrogen as one in sod. He should make his final decison on how much nitrogen to use on the basis of the past history of each tree in the fruit characteristics and yield performance.

Other elements which may be lacking in ordinary orchard soils and may have to be provided for are *potassium, calcium, iron, boron, magnesium,* and *zinc.* Still others like *phosphorus* may become limiting in years to come when the soils are still further depleted of their reservoir of minerals.

Soil Management. There are two extremes of soil management which may be employed in the orchard. One is to leave the trees growing in sod and the other is to practice clean cultivation. Each of these has definite advantages and limitations. Any system of soil management definitely influences tree behavior rather indirectly through its effect on soil water, soil nitrogen, minerals, soil organic matter, and erosion. The exact system or modification of a system that may be used by a given orchardist will depend upon his own situation; for example, sod culture would be out of the question in an irrigated Washington orchard because of the severe competition of the grass for water. On the other hand, even a modification of the cultivation system would be out of the question on the steep hillside of an eastern orchard because of the erosion factor.

Advantages of sod culture

1. Organic matter builds up
2. Checks erosion
3. Less leaching of nutrients

Disadvantages of sod culture

1. Severe competition with the tree for water and nutrients
2. The field mouse problem is considerable

Advantages of clean cultivation

1. Eliminates competition with the tree for water and nutrients by grass and weeds

Disadvantages of clean cultivation

1. Organic matter is depleted
2. Encourages erosion
3. Encourages leaching of nutrients

Both of these systems can be modified to offset some of the disadvantages of each. In a sod orchard *mulch* may be used under the tree to kill the grass and eliminate some competition for water and nutrients. A heavy mulch also encourages water conservation and actually adds some nutrients to the soil. *Mowing* the grass in a sod orchard several times during the summer will also check some water loss induced by transpiration of the grass.

Strip cultivation may be practiced. By this means only every other row of trees is cultivated and hence erosion is checked somewhat.

Cultivation with cover crops is probably the most logical solution to the problem when cultivation during the summer is essential. The usual procedure is to use an overwintering cover crop that holds the soil in place during the fall, winter, and spring. Such a cover crop will also check the depletion of soil organic matter that accompanies clean cultivation.

Pruning. Pruning of apple trees involves the removal of certain branches of the tree for one reason or another. The orchardist must remember not only the purpose of pruning but also the disadvantages of overpruning.

Purposes of pruning

1. To establish a mechanically strong tree by proper spacing of branches
2. To make spraying easier by "opening up the tree"
3. Removal of dead and broken branches
4. To keep the trees from getting too tall for easy picking
5. Sometimes increases fruit size (this can better be done by fruit thinning)
6. To increase fruit coloration by allowing more sunlight to enter the tree
7. To "invigorate" the tree (this might better be accomplished by fertilization, however), by permitting the water and nutrients available in the soil to go to fewer tree branches

Disadvantages of overpruning

1. Delays the time when the tree will start to bear fruit
2. Reduces the yield
3. May increase winter injury
4. Oversized fruit may have more physiological disorders
5. Reduces the size of the tree (this may not always be a disadvantage)

Probably the main purpose of pruning a mature tree is to open it up sufficiently so that it can be thoroughly sprayed. A tree that is too dense cannot be adequately covered with fungicides and insecticides.

Thinning. Thinning involves the removal of excessive amounts of fruit. This may be done in July or early August by hand removal of small fruit or it may be done with some varieties by means of spraying at the time of flowering. Certain sprays (such as dinitrocresol) are applied after some of the flowers have "set" and the sprays prevent further fruit setting. The object of thinning is to get the proper ratio

of leaves to fruit, since the leaves are the main place of food manufacture for the fruit. Another reason for thinning besides reducing the number of fruit, is to make more water available to the fruit remaining.

Purposes of thinning

1. To increase fruit size
2. To increase fruit quality (increased sugar in the fruit, etc.)
3. To increase fruit color (this may be better accomplished by pruning)
4. To reduce limb breakage
5. To remove insect and disease blemished fruit (during hand thinning)
6. To decrease winter injury (since a heavy crop depletes reserves of carbohydrates in the tree)
7. Flower thinning on some varieties may eliminate biennial bearing

Disadvantages of overthinning

1. Oversized fruit is subject to many physiological disorders
2. Oversized fruit is likely to be too soft for long keeping in storage
3. Reduces the yield
4. Oversized fruit does not usually have the market value that sizes normal for the variety have

The exact amount of thinning to be practiced will depend in part upon the variety of apples. Some varieties like McIntosh seem to develop commercially sized fruit with a smaller leaf–fruit ratio than do others like Delicious. The amount of thinning will also depend upon the leaf–fruit ratio at the time of thinning. For example, if the fruit set has been very light because of frost or poor pollination weather, there may be no need of thinning.

Spraying. Apple trees are sprayed with various insecticides, fungicides, or bactericides to control the numerous insects and diseases that attack tree or fruit. The common apple pests and descriptions of the types of damage inflicted on the fruit are summarized in Table 8A. Among the insects there is the *chewing* type which requires a stomach poison for control. Among these are the codling moth, apple maggot, curculio, bud moth, tent caterpillar, leaf roller, and many other less important ones. The most commonly used stomach poison in the past that has been used for these insects has been lead arsenate. DDT is now being substituted for lead arsenate. Nicotine sulfate and cryolite have also been used. Other insects do damage to the tree and fruit by *sucking* juices from the leaves or fruit. Among these are aphids, scale, red bug, red mite, and many other less important ones. The sprays that have been used for these insects include various oils, lime sulfur, nicotine sulfate, and various dinitro materials.

Among the *fungus* diseases, the more important include apple

TABLE 8A. Description of Damage Done by Common Apple Pests

Pest	Type of Damage
	INSECTS
Codling moth	Blossom end injury to fruit, caused by larvae entering through calyx. Side worm injury caused by larvae entering side of fruit, leaving masses of excrement on outside of fruit. "Stings" or shallow pits caused by late season worms.
Curculio	Feeding punctures and egg punctures when healed over leave half-mooned or shield-shaped scar. Larvae may feed on flesh and cause heavy abscission of fruits.
Apple maggot (railroad worm)	Small white maggots tunnel through apple flesh, leaving discolored streaks. Fruit may be honeycombed with tunnels.
European red mite	Sucking of juices from leaves causes typical bronzing of foliage. If unchecked cause premature leaf fall and small fruits.
Red bugs	Feed on young tender leaves and cause small rust-colored spots. On fruits bristles of insects penetrate deeply and cause badly dimpled and misformed fruits.
Rosy aphis	Sucking juice from leaves causes curling and rolling. Fruits are dwarfed, deformed, poorly colored and characteristically puckered at blossom end.
Green aphis	Cover fruit and foliage with sticky honeydew on which a black, sooty, fungus grows.
Bud moth	Young larvae feed on underside of leaves, skeletonizing them in patches along midrib, covering feeding ground with a web of silk. Where an infested leaf rests against an apple the larvae will eat out a group of small cavities.
Fruit tree leaf roller	Caterpillars cause a "ragging" of leaves at tip of shoots. Form web around leaves of blossom clusters and even chew off blossom stems. Eat out large, irregular holes in the fruit. Injuries on mature fruit noted by large, brownish, corky scars which render apples misshapen.
Red-banded leaf roller	Skeletonize leaves by feeding on underside. Eat out shallow irregular channels in fruit just at surface.
Green fruit worms	Young larvae feed on foliage or opening buds. Fruit scars resemble those of red-banded leaf roller but not as deep.
Apple tree tent caterpillar	Defoliate trees. Make webs in which they feed on leaves.

Table continued

TABLE 8A (*Continued*).

Pest	Type of Damage
	INSECTS (*Continued*)
Rose chafer	Eat out holes in apples and make them fall prematurely. Feed on foliage. This insect confined to sandy soil.
White apple leaf hopper	Feed on underside of leaves causing a whitish stippling on the upper surface. Second brood may speckle the fruit with excrement.
San Jose scale	Reddish rings develop around the spots where the scales are attached on the fruit. Make a roughened scurfy deposit on the bark.
Oyster shell scale	Mature female scale resembles oyster shell in form. Feed on bark of tree, sucking out juices.
Scurfy scale	Give bark a scurfy appearance where they feed. Fruit may be spotted similar to San Jose scale injury.
Case bearers	Make cigar-shaped case from which they protrude their heads and feed on leaves.
Periodical cicada	Females deposit eggs in branches of young trees, weakening them so that they break off easily in winds.
Wooly aphid	Above ground aphids cluster in wounds in the bark and cause enlargements and scars on branches. Bear white cottony masses of wax threads. Root-inhabiting individuals cause knotlike swelling on roots and may even kill tree. Below ground individuals do not bear long cottony threads but are covered with a white mealy wax coating.
Flat-headed apple tree borer	Excavates broad, shallow burrows in sapwood just beneath bark and often girdles young trees. Works from ground up to lower limbs.
Round-headed apple tree borer	Bore into tree at ground or below ground level.
	DISEASES
Scab	Fungus causes olive-colored, velvety areas on young leaves and fruit sepals. On fruits first appear as small circular, olive-colored areas; later typical blackish raised areas appear, sometimes causing fruit cracking. Some fruit lesions may become corked over.
Apple rust	This fungus makes bright orange-colored spot usually in calyx end of fruit.
Quince rust	Fungus makes sunken, dark green spots on fruit. Tissue beneath spots is killed. Puckers end of fruit to make it look somewhat like a quince.

Table continued

TABLE 8A (*Concluded*). Damage Done by Common Apple Pests

Pest	Type of Damage
DISEASES (*Continued*)	
Black rot	Fungus attacks bark and leaves and sometimes the fruit. On leaves it makes a "frog-eye" appearance. May cause severe defoliation.
Brooks fruit spot	Fungus makes spots which are red or black on red areas of fruit and dark green spots on yellow areas of fruit. Center of spot usually flecked with black. Spots are irregular in outline, slightly sunken, and usually more abundant near calyx end of fruit.
Sooty blotch	Fungus causes sooty brown or black spots or blotches on fruit.
Fly speck	Fungus causes shiny, black dots resembling fly specks.
Fire blight	Bacterial disease affecting flowers, shoots, and trunks. Causes "blighting" of the flowers. Infected branches turn dark colored, leaves wilt, dry up and cling tightly to dead twigs. Branches look as though they had been burnt by fire. Cankers formed on branches.
Crown gall	Bacterial disease causing galls on roots of trees Galls often prominent at the graft union.
ANIMAL PESTS	
Rabbits	Chew bark off trunk as high as they can reach. Often girdle trunk.
Field mice	Chew bark off trunk as high as they can reach. Often girdle tree.
Pine mice	Chew bark off roots and kill them by girdling them.
Deer	Eat off tender shoots.
Partridge	Eat off buds of tree in dormant season.

scab, cedar rust, sooty blotch, fly speck, and Brooks spot. The most commonly used fungicide has been sulfur. This has been used as lime sulfur or elemental sulfur in various ways. Copper sulfate (in Bordeaux mixture) is used for certain fungus troubles. The most common *bacterial* diseases of apples are fire blight and crown gall. The former is partly controlled (through reduction of blossom infection) by use of Bordeaux mixture although other means of control are more important. There are some *virus* diseases of the apple but they are not very important.

There are many other pests of the apple which are not controlled

by spraying. These pests also may markedly affect the physiology of the tree and the composition of the fruit. For example, mouse injury may completely girdle a tree and result in reduced nitrogen supply to the top of the tree and even death to the tree if the injury is not repaired.

These insecticide and fungicide sprays may have an effect on the tree and fruit both directly and indirectly. For example, a fungicidal spray like flotation sulfur protects the leaves against scab so that normal photosynthesis can take place. A scab infested tree would be expected to be low in fruit sugars because of reduced photosynthesis. An indirect effect may result from the use of a spray. For example, the use of lime sulfur may burn out scab spots on the leaves and yet result in enough injury to the leaves so that photosynthesis is again retarded.

Sprays other than those including insecticides and fungicides may be used on apples. A spray to *thin the flowers* has already been mentioned. Another spray is the use of naphthalene acetic acid prior to harvest to *reduce the premature dropping* of the fruit. Other sprays which are still in the experimental stages are those which may break the dormancy of the tree or those which may retard flowering in the spring to escape frosts.

Rootstocks. Apple trees will not come true from seed. That is, when the seed of a McIntosh apple is planted there is something like one chance in a million that a McIntosh tree will result. This is true even when a McIntosh flower is self pollinated (with McIntosh pollen) and the resulting seeds are planted. Hence, apple trees must be propagated vegetatively, that is, instead of planting seeds, pieces of the mother tree are propagated on one or two year old rootstocks. Buds are transplanted from the mother tree either by grafting or budding. The rootstocks used may be a seedling tree since the orchardist is not primarily interested in the characteristics of the roots. It has been a common practice to bud or graft on to seedling trees of French Crab or seedling trees of some of our domestic varieties like Northern Spy. The seeds of these varieties are planted and when they get to be one or two years old they are grafted or budded to the desired variety.

When the orchardist wants to control the characteristics of the rootstock he uses vegetatively propagated stocks. There is a wide genetic variation in seedling rootstocks and, while such stocks have proven generally satisfactory for commercial purposes, the fruit

grower may want to control the size of his apple trees. The vegetatively propagated rootstocks have been classified as to the size of the tree that will grow on them by the East Malling Research Station in England and hence have been called the Malling stocks. For example, Malling XII stocks result in large vigorously growing trees, Malling II in a semidwarf tree, and Malling IX in a very dwarfed tree.

Ringing. This involves the removal of a strip of bark about a quarter of an inch wide from the trunk or large branch of an apple tree. It is usually done on trees that are extremely slow in starting to flower. Ringing in late May will often induce flower formation on such trees. It is occasionally done to increase fruit setting in some varieties that have already started to flower. Ringing checks the upward movement of nitrogen compounds from the roots and checks the downward movement of carbohydrates. The wound heals within a month or two so the effect is only temporary. If ringing is practiced on a bearing tree it is obvious that it might affect the chemical composition of the fruits.

Other Cultural Practices. There are many other less important cultural practices which may affect the composition or physiology of the fruit. These are too numerous to mention in a text of this kind. An illustration of the less important practices that might affect fruit composition or fruit physiology is the *distance of planting.* If the trees are too closely planted, when they attain maturity or full size the branches may be actually interlacing. Even though the condition is not acute there is severe shading of the lower branches as a result of the close planting. This shading could obviously affect the fruit.

Another illustration is the use of *bees* for pollination purposes. If bees are not present pollination is inadequate and fruit set is light. A light fruit set means a wide leaf–fruit ratio with its resultant effects on fruit composition.

CHAPTER V

CHEMICAL CHANGES AND PHYSIOLOGY OF APPLE FRUIT ON THE TREE

While the food technologist, fruit grower, and consumer are primarily interested in the composition of apples after they are harvested, we can best understand the behavior of the fruit after harvest if we know the changes which it has undergone while on the

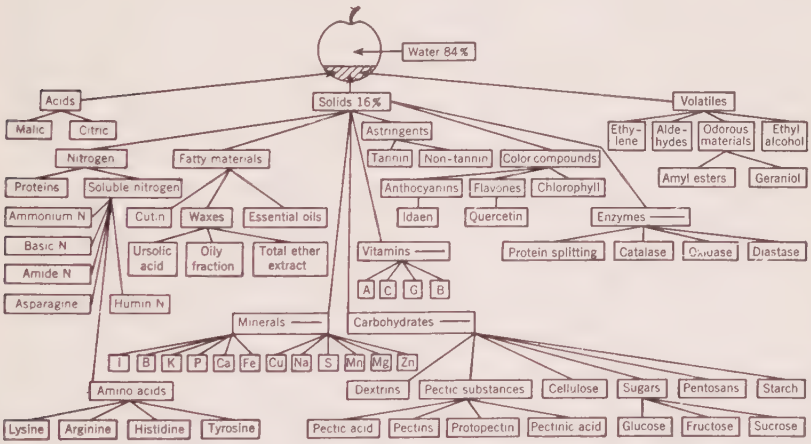


Fig. 6. Chemical composition of apples.

tree. Some of the climatic, cultural, and tree factors which may affect the chemical composition and physiology of the developing fruit will be discussed in this chapter (Fig. 6).

A. Water

We are interested in the water content of apples at harvest time for several reasons. Since the apple is composed so largely of

water, it is obvious that *size* increase will depend in large part on the total amount of water present in the fruit. Water content helps determine in part the *eating quality* of the fruit.

As apple fruits mature on the tree and increase in size there is an obvious increase in the total amount of water present. That is, the absolute amount of water in the fruit increases steadily as the fruit develops on the tree. There is a slight decrease in water in the apple fruits on a percentage basis, however. Conversely, the percentage of total solids increases slightly as the apples mature.

It will be noted in Figure 7 that there is only a slight decrease in percentage of water as the fruit matures.[26] However, a decrease as

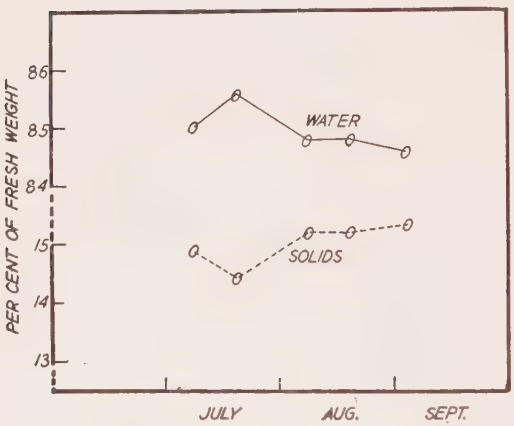


Fig. 7. Changes in the percentage of water and solids in Stayman Winesap apples during the growing season.[26]

much as 2.5% has been noted during the growing season in Australian apples (*i.e.*, a drop from 87.0 to 84.5%).[27]

The percentage of water in different varieties of apples varies somewhat. A range (in percentage) of water between varieties from 78.9 to 90.9 has been reported.[28] Table 9 lists some differences in water content in apples of various varieties as grown in Ohio. It should be noted when varietal differences are compared that the comparison should probably not be made at the same calendar date but rather at the same stage of fruit maturity. For example, McIntosh

[26] E. F. Hopkins and J. H. Gourley, *Ohio Agr. Expt. Sta. Bull.*, 519, 1933.
[27] H. O. Askew, *J. Pomol. Hort. Sci., 13*, 232 (1935).
[28] C. Chatfield and C. I. McLaughlin, *U. S. D. A. Circ.*, 50, 1931.

may have been more mature when examined on July 30 (see Table 9) than the Winesap.

Transpiration is the loss of water from living tissues in the vapor form. The leaves are the main transpiring organs of an apple tree

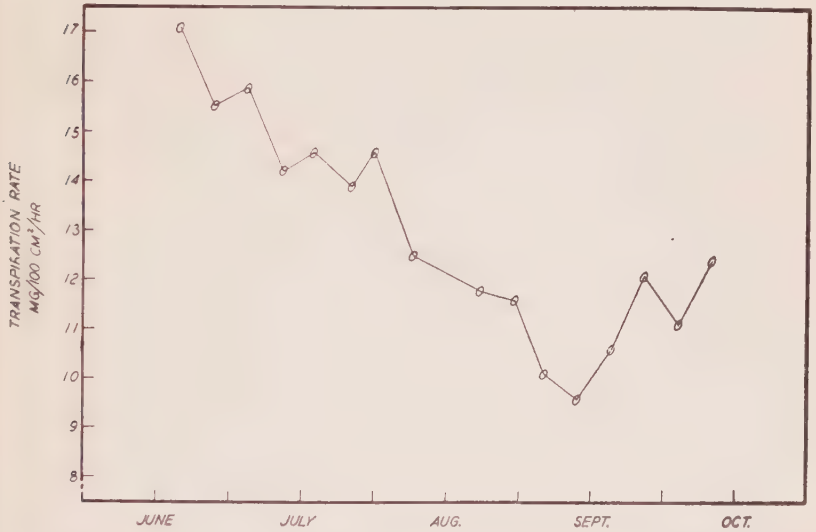


Fig. 8. Transpiration rate of Baldwin apples during the growing season; measured at 77°F. (25°C.) and 63% relative humidity.[29]

TABLE 9. Moisture and Percentage of Solids in Various Ohio Grown Varieties (July 30, 1931)[26]

Variety	Water, %	Solids, %
Grimes Golden	83.62	16.38
McIntosh	87.27	12.73
Jonathan	85.98	14.02
Stayman	85.24	14.76
Winesap	84.82	15.18

but the fruits transpire also. While the fruits are very small, transpiration is very rapid (see Fig. 8). This rapid transpiration may be due to the fact that the fruits are small and transpiration is really a surface phenomenon and can best be expressed on a surface area basis.[29]

[29] S. A. Pieniazek, *Proc. Am. Soc. Hort. Sci., 42,* 231 (1943).

TABLE 10. LEVULOSE, DEXTROSE, AND SUCROSE CONTENT OF FIFTEEN APPLE VARIETIES AT OPTIMUM MATURITY[38]

Variety[a]	Grams per fruit[b]	Per cent of fresh weight				Grams per fruit				Per cent of dry matter
		Levulose	Dextrose	Sucrose	Total sugars	Levulose	Dextrose	Sucrose	Total sugars	
Yellow Transparent A	89.46	4.58	1.11	2.51	8.20	4.10	0.99	2.25	7.34	12.40
Yellow Transparent B	84.68	4.36	1.18	1.42	6.96	2.69	1.00	1.20	5.89	12.20
Red June	104.54	3.84	1.42	3.62	8.88	4.01	1.48	3.78	9.28	13.10
Williams	88.13	4.66	1.57	2.63	8.86	4.11	1.38	2.32	7.81	13.45
Lodi	126.37	5.20	1.39	2.58	9.17	6.57	1.76	3.26	11.59	13.00
Sweet Bough	169.00	6.16	1.35	3.98	11.49	10.41	2.28	6.73	19.42	15.50
Wealthy	132.06	4.97	0.95	2.30	8.22	6.56	1.25	3.04	10.86	12.60
Starking	166.62	5.73	1.27	2.39	9.39	9.55	2.12	3.98	15.65	16.65
Cortland	177.62	5.44	1.38	2.47	9.29	9.66	2.45	4.39	16.50	14.50
Jonathan	163.70	5.90	2.00	2.80	10.70	9.66	3.27	4.58	17.52	16.20
Grimes	130.40	4.91	0.88	3.20	8.99	6.40	1.15	4.17	11.72	14.95
Golden Delicious A	175.94	6.40	1.77	3.62	11.79	11.26	3.11	6.37	20.74	16.45
Golden Delicious B	165.08	5.41	1.83	2.58	9.82	8.93	3.02	4.26	16.21	13.40
Delicious	183.00	5.08	1.94	2.98	10.00	9.30	3.55	5.45	18.30	14.20
Stayman	226.97	4.78	2.00	2.38	9.16	10.85	4.54	5.40	20.79	15.60
Winesap	145.67	5.30	2.70	2.93	10.93	7.72	3.93	4.27	15.92	16.00
Willowtwig	197.46	4.32	1.79	3.98	10.09	8.53	3.53	7.86	19.92	16.40

[a] All samples from University orchard at Urbana, Illinois, with the following exceptions: Yellow Transparent B and Williams from Johnson County; Red June from Union County; Cortland and Starking from McLean County; Golden Delicious B from Pike County, Illinois.

[b] Seed and stem not included.

Small fruits have a greater surface area per unit of weight than large fruits. The rapid transpiration of young or small apple fruits may also be attributed to the presence of numerous epidermal hairs and to the fact that there is very little cuticle development on young fruits.

The normal transpiration rate in Baldwin apples has been shown to drop steadily from early summer until early September when it starts to rise again.[29] Why the transpiration rate should start to rise when the apples become almost mature on the tree is not known.

B. Carbohydrates

1. SUGARS

Sugars constitute the major portion of the carbohydrate material in apples. They also constitute most of the soluble solid material in the flesh of the apple. Sugars are manufactured in the leaves by the process known as *photosynthesis* and are translocated to the fruits. Just how much sugar may be synthesized in the growing fruit is not known. There is chlorophyll in the skin of the young fruit so it would seem possible that some photosynthesis might occur there. The quantity of chlorophyll present in the fruit is so much less per unit area than that in the leaf that it is understandable why only a small fraction of the sugars synthesized might come from the fruit. The structure of the fruit skin is not adapted to ready diffusion of gases as is that of the leaf. In unpublished work by the senior author (R. M. Smock) it has been shown that some sugars may be manufactured by the fruits, however. Fruits shaded with individual white paper shades did not develop as much sugar as those without such shades; this was probably due to the exclusion of light.

The sugars found in the flesh of the apple are *fructose* (levulose), *glucose* (dextrose), and *sucrose* (Table 10). The exact proportions of these various sugars in the apple depend upon the variety and other factors.[30] Fructose and glucose both increase in absolute amount and in percentage of fresh weight as the fruit develops on the tree. In one study with Bramley Seedling apples the amount of fructose was double that of glucose at harvest time.[31] In English "eating apples" it was found that there was at harvest time 2.20% of

[30] D. I. Evans, *Ann. Botany, 42,* 1 (1928).

[31] D. Haynes and H. K. Archbold, *Rept. Food Investigation Board,* 1929, 106 (1930).

glucose, 7.25% of fructose, and 2.70% of sucrose.[32] Fig. 9 illustrates the increase in reducing sugars (fructose and glucose) and sucrose in apples as they matured on the tree.[33]

The sugars in apple fruits are not equally distributed in all parts of the fruit. It has been found that the amount of total sugars increases as one samples from the core to the outside and increases in

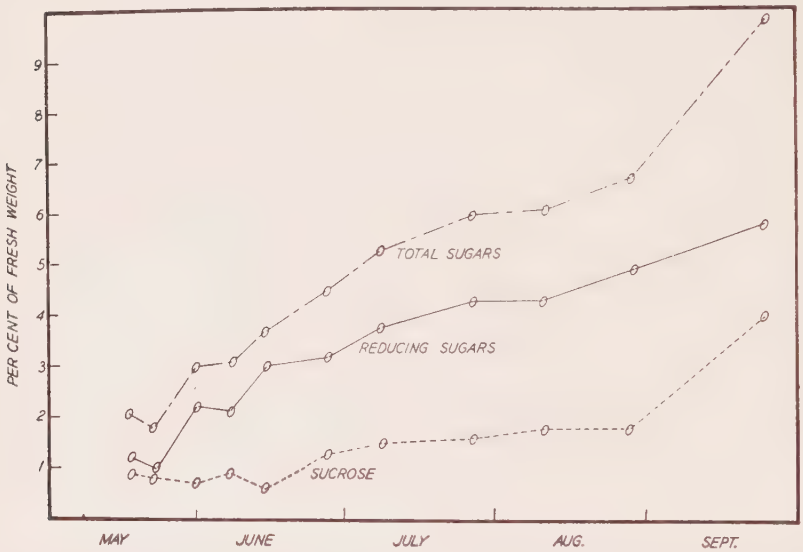


Fig. 9. Changes in the total sugars, reducing sugars, and sucrose in Baldwin apples during the growing season.[33]

amount as one samples from the stem to the calyx end.[34 35] It has also been found that the blushed (colored) side of an apple has more sugar than the unblushed side.[35]

Factors Affecting Sugar Content in Apples. Since the apple fruits are dependent for the most part on the leaves[36] as their source

[32] D. I. Evans, *Ann. Botany, 42,* 1, (1928).
[33] J. S. Caldwell, *U. S. D. A. Tech. Bull.,* 403, 1934.
[34] P. Harding, *J. Agr. Research, 53,* 43 (1936).
[35] H. K. Archbold and A. M. Barker, *Ann. Botany, 48,* 957 (1934).
[36] M. H. Haller and J. R. Magness, *Proc. Am. Soc. Hort. Sci., 22,* 189 (1926).

of sugar, it is not surprising that the *leaf–fruit ratio* may affect the sugar concentrations in the fruits. Figure 10 illustrates the effect of number of leaves per fruit on sugar percentage in apples. Of course, a point of diminishing returns is finally reached beyond which more leaves per fruit do not result in sugar increases. Fruits grown on individual limbs from which all the leaves have been removed may reach full size but they do not have their full complement of sugars.[37]

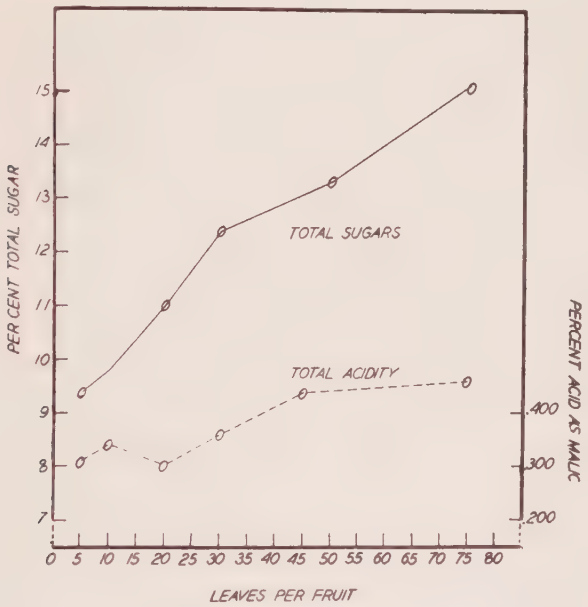


Fig. 10. Relation of leaf–fruit ratio to the total sugars and total acidity in Ben Davis apples at harvest time.[36]

Such fruits get their necessary sugars from adjacent limbs which have leaves. Of course, when fruits are grown on limbs that have been defoliated and ringed, fruit size as well as sugar content are markedly affected.

Obviously the *variety* of apples will affect the amount of total sugars or proportions of various constituent sugars.[38] In a study of

[37] R. M. Smock, *Cornell Univ. Agr. Expt. Sta. Mem.*, 234, 1941.
[38] R. V. Lott, *Proc. Am. Soc. Hort. Sci., 43,* 56 (1943).

a large number of American varieties the range in total sugars was from 6.6 to 15.9%.[39]

Sugar content has been found to vary in apples from location to location or from orchard to orchard.[30,40] These differences may be attributed to soil or climatic variations or both. In one study it was shown that the sugar content in a given variety varied more from orchard to orchard than it did between varieties in the same orchard.[30]

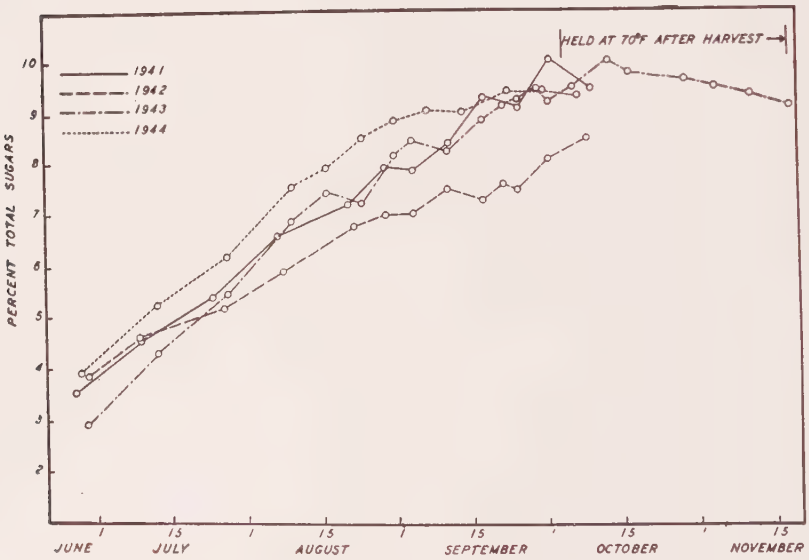


Fig. 11. Changes in total sugars in McIntosh apples during the growing periods of four seasons in the same orchard. The 1943 lot was held at 70°F. (21°C.) following the commercial harvest date to observe changes in total sugars.

The amount of sugars also varies from *season to season* within the same variety in the same location (see Fig. 11). In a study of 216 varieties over a period of four to six years it was found that the sugar content of the juice varied considerably from year to year.[41] As might be expected, those climatological features which result in high photosynthetic activity result in high sugar content in the juice of the fruit. Recorded weather data showed that warm temperatures and high light intensity and duration resulted in the maximum

[39] C. Chatfield and C. I. McLaughlin, *U. S. D. A. Circ.*, 50, 1931.
[40] F. W. Allen, *Hilgardia, 6,* 381 (1932).
[41] J. S. Caldwell, *J. Agr. Research, 36,* 289 (1928).

concentration of fruit sugar. The temperature and light characteristics of the first four months of the growing season seemed especially important in determining the concentration of sugar in the apple. The amount of rainfall fluctuated considerably from year to year but water supply had little effect if any on sugar content unless soil moisture was actually a limiting factor. In one year, when water was so deficient in the soil that the trees showed incipient wilting at times, the sugar content of the fruit for that season was quite low in spite of the high temperatures and good light that prevailed. Under such water-deficient conditions, the stomata of the leaves close and carbon dioxide is actually a limiting factor.

The effect of *nitrogen fertilizers* on the sugar content of fruit is not entirely clear. In one study it was reported that there was a higher total sugar content in two varieties of apples when fertilized with nitrogen.[42] This effect seemed to be due to a higher content of sucrose and not to any influence on reducing sugars. In another study it has been shown that nitrogen additions to the soil might reduce the osmotic concentration of the juice of apples (osmotic concentration is largely due to the sugars present).[37]

In a study of McIntosh from five orchards over a period of two years there was a suggestion of reduced soluble solids content in the fruit in several orchards when the nitrogen level of the tree was increased.[43] There was no suggestion of increased soluble solids in the fruit in any orchard as a result of nitrogen additions to the soil. In an Ohio study there was no marked effect of nitrogen application on the soluble carbohydrates present in apple fruits although there was a suggestion of reduced sugars in the fruits when large applications were used.[44] This was doubtless due to the fact that more sugars were utilized in growth. In interpreting the effects of nitrogen fertilizers on sugar content of the fruit one has to keep in mind that the magnitude of such effects depends in large part on the nitrogen level of the tree at the time of treatment. Another thing to keep in mind is that if nitrogen additions actually increase fruit set there may be a reduction in fruit sugar percentage because of the lessened leaf–fruit ratio.

There is not much information on the effect of *pruning* on the sugar content of apple fruits. In one experiment in England heavy

[42] T. W. Wallace, *Univ. Bristol Agr. Research Sta. Spec. Rept.*, 1930.
[43] R. M. Smock and D. Boynton, *Proc. Am. Soc. Hort. Sci., 45,* 77 (1944).
[44] E. F. Hopkins and J. H. Gourley, *ibid., 27,* 32 (1930).

spur pruning resulted in somewhat higher sucrose in Allington Pippin apples when compared to a lighter thinning-out type of pruning.[42]

The effect of *water supply* in the soil or irrigation on the sugar content of apples would doubtless depend upon the degree of water deficiency in the soil. In one study it was found that irrigation of apple trees suffering from drought resulted in an increase in the total sugar of the apples.[45] In an Idaho study it was found that irrigation resulted in decreased sugar in apples.[46] It should be pointed out, however, that in this last study the irrigated and non-irrigated trees were in different localities. Differences in sugar in this case may not have been due solely to variations in irrigation practice. The result that most logically would be expected from water additions (assuming non-drought conditions) would be a dilution of the sugars present since size is increased by water additions. For example, in one of the more exhaustive studies of this sort it was found that with ample soil moisture there was a 38% increase in the amount of water in the fruit.[47] This meant that on a fresh weight basis the ample water supplies reduced the per cent of solids (mostly sugars) in apples.

Ringing of tree limbs has been found to increase the sugar content of apple fruits, but this practice would hardly be recommended for this purpose.[42] Ringing involves removal of the phloem, the tissue responsible in large part for the translocation of sugars.

Spraying with fungicides protects the leaves of the apple tree against fungal invasion so that photosynthesis can proceed normally. Hence, the fruits will get their full complement of sugars unless some other factor is limiting. On the other hand, if fungicides that are toxic to the leaves are used, it is logical to expect that fruit sugars may be lowered.

2. POLYSACCHARIDES

Starch. Starch consists of two fractions composed of anhydroglucose units. One of these (amylopectin) contains a branched structure while the other (amylose) is built in the form of a straight chain. Which of these compounds predominates in apple starch is not known.

[45] H. H. Plagge, *Proc. Iowa Acad. Sci., 42,* 77 (1935).
[46] J. S. Jones and C. W. Colver, *Idaho Agr. Expt. Sta. Bull.,* 75, 1912.
[47] J. R. Magness, E. S. Degman, and J. R. Furr, *U. S. D. A. Tech. Bull.,* 491, 1935.

Starch is deposited in the apple fruit very early in its development on the tree. Sugars presumably are transported for the most part from the leaves (only a small amount of sugars being formed in the fruits) and starch is formed in the fruits. Starch is often called a "storage" material since it must be broken down or hydrolyzed before it can be used in plant metabolism.

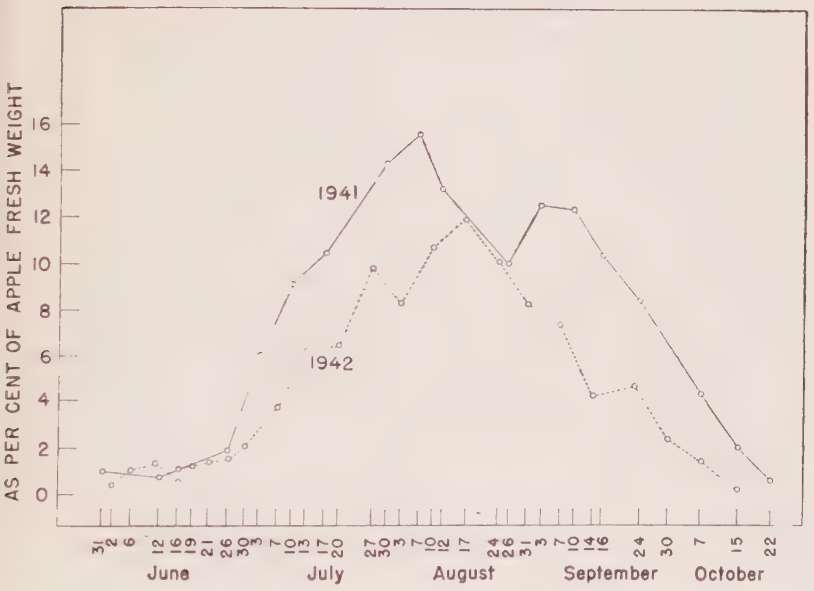


Fig. 12. Starch changes in McIntosh apples during the growing season.[53a]

Starch deposition begins in the cell layers near the skin and proceeds toward the core. As the fruits mature on the tree and starch begins to hydrolyze into sugars, the starch disappears first from the core areas and last from the areas just under the skin.[35] This decrease in starch percentage usually begins a few weeks before harvest. The loss in starch (hydrolysis to sugars) takes place quite rapidly during ripening. There may be a small amount of starch left by harvest time or there may not be any left (see Fig. 12).[48]

[48] W. D. Bigelow, H. C. Gore, and B. J. Howard, *U. S. D. A. Bur. Chem. Bull.*, 94, 1905.

The starch content of apples varies from variety to variety and from season to season within a given variety.[41] Starch content of apple juice was found to be high at harvest time in years when there was low light duration and intensity and relatively low temperatures during the growing season. The sugar content was low in the fruits during these particular years as a result of lessened photosynthesis. Starch levels seemed to be rather high, however. Caldwell thought that the starch level was high because diastase (the enzyme which breaks down starch) activity was low.[41]

Ringing of limbs of the tree in early summer has been found to increase the starch content of apples at harvest time.[49]

Pectic Substances. No attempt will be made here to discuss the subject of pectin chemistry in detail since a full discussion of this topic is available in another book.[50]

The pectic substances might be briefly outlined as follows.[50] The general term *pectic substances* is a group designation for those complex, colloidal carbohydrate derivatives which contain a large proportion of anhydrogalacturonic acid units which are thought to exist in a chain like combination. The carboxyl groups of polygalacturonic acids may be partly esterified by methyl groups and partly or completely neutralized by one or more bases. The term *protopectin* is applied to the water-insoluble parent pectic substance which upon hydrolysis yields pectin or pectinic acids. *Pectinic acids* is a term used for colloidal polygalacturonic acids containing more than a negligible proportion of methyl groups. These acids under suitable conditions are capable of forming jellies with sugar and acid or, if suitably low in methoxyl content, with certain metallic ions. The term *pectin* designates those water-soluble pectinic acids of varying methyl ester content and degree of neutralization which are capable of forming jellies with sugar under suitable conditions. The term *pectic acids* is applied to pectic substances mostly composed of polygalacturonic acids and essentially free from methyl ester groups. The salts of pectic acids are either normal or acid pectates.

The use of apple powder in the treatment of diarrhea is widely recognized. This corrective action of apples in the diet is partly due to the pectic content and partly due to the presence of certain fibrous materials.[50a] These substances are also of interest because of their

[49] M. Onslow, F. Kidd, and C. West, *Rept. Food Inv. Board, 1932,* 70 (1933).
[50] Z. I. Kertesz, *The Pectic Substances.* Interscience, New York, *in preparation.*
[50a] Z. I. Kertesz, M. S. Walker, and C. M. McKay, *Am. J. Digestive Diseases, 8,* 124 (1941).

importance in fruit technology and processing. They are also important because of their presence in the middle lamella and cell walls of the apple flesh. The cells of the apple are cemented together with protopectin and as the fruits ripen and soften there is a lessening of the cementing action. The cells become less firmly cemented together as insoluble pectin (or protopectin) is hydrolyzed into soluble pectin. At least in many species this phenomenon has long been used as an explanation of softening or maturation. This relationship between pectic changes and softening seems to hold much better in apples after harvest than during maturation on the tree. It has been found that in growing apples, factors other than pectic changes may be of more importance in determining softening.[51] Increases in cell size and changes in size and shape of intercellular spaces are among the factors which doubtless affect softening of apple fruits on the tree. Another important factor is doubtless the thickness of the cell walls. This does not mean that pectic changes may not be involved in softening of fruits while on the tree but it does mean that other factors seem more important.

The pectic compounds in apples may be described as follows. Protopectin seems to be one of the constituents of the cell wall and middle lamella. This insoluble material is hydrolyzed into soluble pectinic acids and pectins. The assumed agent of the hydrolysis of protopectin, the enzyme protopectinase, has not yet been found in apples. It has been found, however, that this hydrolysis could be accomplished by ascorbic acid or peroxides. The hydrolysis was especially rapid when both these materials were present.[51a,52] While this may or may not be the mechanism of the breakdown of protopectin in apples, it is known that ascorbic acid is present in apples and that peroxides are present. The pectinic acids may be broken down or hydrolyzed into pectic acids. In this action there is a splitting off of methyl groups. This action in apples was long presumed to be due to an enzyme called pectin-methylesterase (formerly called "pectase") but this enzyme has not been found in apples.[51a] The disappearance of pectic compounds in the apple is assumed to be the result of the hydrolytic action of the enzyme pectinase (pectin-polygalacturonase). Again there is no definite evidence that this enzyme is present in the apple. Protopectin is thought to be composed of pectinic acids of very large molecular weight and agents attacking pectinic acid will

[51] M. H. Haller, *J. Agr. Research, 39,* 739 (1929).
[51a] J. H. Griffin and Z. I. Kertesz, *Botan. Gaz., 108,* 279 (1946).
[52] Z. I. Kertesz, *Plant Physiol., 18,* 308 (1943).

therefore probably attack protopectin.[51a] The term "*total pectin*" is used to cover all pectin compounds. Since none of these pectin enzymes have been found in apples one wonders how these pectic changes take place. There is evidence to indicate that all three of the pectic changes described may be caused by ascorbic acid or peroxides.[51a,52]

Analyses of pectic constituents in apples as they mature on the tree have not been in good agreement among various investigators. This lack of agreement may have been due to the fact that different varieties and different growing conditions were involved. In English grown Bramley Seedling apples there was a rapid decrease in the percentage of total pectic constituents early in the life of the apple on the tree but after mid-June the percentage remained fairly constant.[53] In constrast to this finding, it was found that in American grown Jonathan apples the total pectic substances were constant throughout the season until the fruit started to soften enough to require only 15 pounds for the pressure test.[51] After that time the total pectic substances decreased. With Ben Davis apples the percentage of total pectic materials decreased steadily throughout growth of the fruit on the tree. In both varieties it was found that the soluble fraction of pectic materials remained constant during growth but that in Jonathan there was a decrease in the insoluble fraction.

In unpublished work by the senior author (R. M. Smock) with McIntosh it was found that the soluble pectin fraction increased slightly during one season but remained fairly constant during another. This indicates that the growing season may also affect pectic changes.

Pectic changes in apples while on the tree may be summarized as follows. These changes seem to vary considerably with different varieties and under different conditions. Such changes cannot be used as a good index of softening rate while the fruit is still maturing on the tree. Anatomical changes such as cell enlargement and lessening of cell wall thickness are probably as important or more important than pectic changes in explaining fruit softening on the tree.

Cellulose. Cellulose is a term that describes a class of compounds built from anhydroglucose units lined up in long chains. The customary method of determination of "crude fiber" often used for cellulose includes a small proportion of other compounds such as *lignins*. Cellulose is of importance because it is one of the main constit-

[53] E. M. Widdowson, *Ann. Botany, 46,* 597 (1932).

uents of the cell walls of apple flesh. As apples develop on the tree it is obvious that the total cell wall material would increase. In a limited number of studies made on cellulose changes in apple tissue it was found that there was a slight increase in the percentage composition of this material. There seemed to be about 1% cellulose on a fresh weight basis in the four varieties that were analyzed at harvest time.[48]

Hemicelluloses. Hemicelluloses are polysaccharides composed of hexosans, pentosans, and uronic acids or mixtures of these. It has been found in McIntosh apples that the percentage of hemicelluloses was high early in the development of fruits on the tree. The percentage declined rapidly at first and then more slowly, reaching a steady value by harvest time.[53a]

Pentosans. The pentosans might be described as being composed of an indefinite number of anhydropentose units, usually arabinose or xylose. The real significance of the pentosans in apple physiology is not known. In a study of two varieties the amount of pentosans ranged between 0.80 and 1.15% of the fresh weight. There seemed to be little change in the percentage composition during the month prior to harvest.[48]

Dextrins. The term dextrin is used as a collective name for a group of intermediate products formed by the partial hydrolysis of starch. They are distinguished from starch by the fact that they are soluble in cold water and from sugars by the fact that they may be precipitated with alcohol.

Dextrins in Grimes Golden apples were found to decrease from mid-August until October although there was a marked fluctuation in this decrease. By October no dextrin could be found in this variety. The highest amount present at any time was about 4.0% of the dry weight.[54]

C. Acids

The acid in the fruit of the apple is primarily malic although other acids such as citric have been reported.[55,55a] The carboxyl groups of pectic substances are sufficiently esterified or engaged in

[53a] G. Krotkov and V. Helson, *Can. J. Research, 24,* 126 (1946).
[54] H. H. Plagge, A. J. Maney, and F. Gerhardt, *Iowa Agr. Expt. Sta. Bull.*, 91, 1926, pp. 43–71.
[55] W. D. Bigelow and P. B. Dunbar, *J. Am. Chem. Soc., 9,* 762 (1917).
[55a] H. Franzen and F. Helwert, *Z. physiol. Chem., 127,* 14 (1923).

salt formation to make their contribution to the total acidity of the fruit insignificant. Other acids like ascorbic, oxalic, and lactic are present in such small amounts that they would not contribute very much to the acidity of the fruit. It is probably true that malic and citric acids make the major contributions to the acidity of the apple. The acid fraction of the fruit is of interest because it affects eating and cooking quality and is of importance in apple products. Apples as eaten have an acid reaction but because of their buffering capacity influence the acid–base balance of the body as an alkaline food.[55b] The organic acids of the apple are oxidized in the body to furnish energy and leave a basic residue in the blood. The large amount of base-forming elements (potassium, calcium, magnesium, and sodium) in the apple leads to the formation of a urine less acid than normal. The apple in human nutrition thus safeguards the body against reduction of the bicarbonate concentration or alkali reserve in the blood.[56]

Acidity may be expressed as the total titratable acids or as hydrogen ion concentration. The latter is expressed in terms of *p*H which is the logarithm of the reciprocal of the hydrogen ion concentration. On the *p*H scale a value 7.0 is neutral. Values below 7 are acid and those above alkaline. Since these values are expressed as logarithmic ones, each number indicates a tenfold increase in hydrogen ion concentration as the number decreases by one.

The actual or absolute amount of acid present in the apple increases steadily as the fruit enlarges on the tree until just before harvest when there is a slight decline.[57]

The titratable acidity steadily decreases as the fruit matures on the tree.[58,59] The *p*H rises steadily as the fruit develops but the rise is not very striking. One study[60] reported a considerable fluctuation in *p*H as the fruits matured on the tree but in general there was an increase (*i.e.*, less acid). On a percentage basis, the malic acid content of English grown Bramley Seedling apples was shown to decrease from 2.0 to 1.0% of fresh weight during the growing season.[61]

[55b] W. B. Esselen, Jr., C. R. Fellers, and M. S. Gutowska, *Mass. Agr. Expt. Sta. Bull.*, 440, 1947.
[56] K. G. Shea and C. R. Fellers, *J. Am. Dietet. Assoc., 18,* 454 (1942).
[57] A. C. Hulme, *Biochem. J., 30,* 258 (1936).
[58] W. D. Bigelow, *U. S. D. A. Bur. Chem. Bull.,* 66, 1906.
[59] J. S. Caldwell, *U. S. D. A. Tech. Bull.,* 403, 1934.
[60] O. Einset, *Gartenbauwiss., 11,* 319 (1937).
[61] H. K. Archbold, *Rept. Food Inv. Board, 1930,* 194 (1931).

Acidity varies considerably from *variety* to *variety*. In a Massachusetts study the *p*H of the juice of eight varieties was shown to range from 3.18 to 3.60 while the total acidity ranged between 0.38 to 1.11%.[62] In another study of varietal differences the range was from 0.1 to 1.15% although the maturity at the time of sampling was not stated.[63] In a study of 33 Minnesota grown varieties the *p*H range was from 3.03 to 5.40 and the titratable acidity from 0.026 to

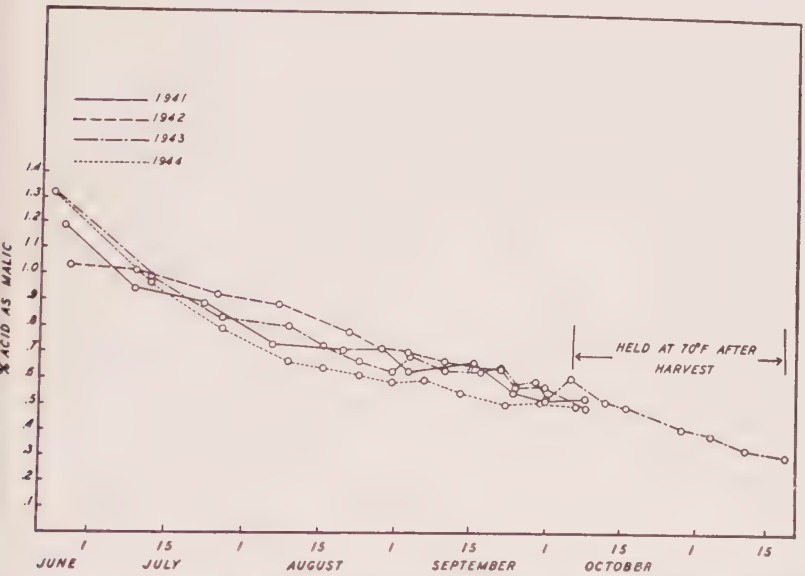


Fig. 13. Changes in total acidity of McIntosh apples during the growing periods of four seasons in the same orchard. The 1943 lot was held at 70°F. (21°C.) following the commercial harvest date to observe changes in total acidity.

1.45%. When the data in this study were treated statistically a strong correlation was found between the *p*H and the titratable acidity (*r* equals 0.9265).[64] Such a strong correlation was not found to be the case in an Australian study, however.[65]

In a study of the juice of 216 varieties of apples over a period of four to six years it was found that acidity varies considerably from

[62] C. R. Fellers, *Mass. Agr. Expt. Sta. Bull.*, 15, 1928.
[63] C. Chatfield and C. I. McLaughlin, *U. S. D. A. Circ.*, 50, 1931.
[64] E. O. Barnes, *Minn. Tech. Bull.*, 143, 1940.
[65] H. O. Askew, *New Zealand J. Sci. Technol., 18*, No. 2 (1936).

season to *season*.[41] While acidity was not as markedly affected by seasonal conditions as sugars, it was affected to some degree. It was noted in particular that following a season of high light intensity and duration (much sunshine) the acidity was high (as well as sugar content). This situation of high sugar and high acidity was usually accompanied by a low relative astringency and hence sweet or mild tasting apples. In another study by the senior author (Smock) of seasonal variations in McIntosh apples it was shown that there were fluctuations in total acidity. These results (expressed as malic acid) are presented in figure 13.

Apple tissue or juice has a considerable *buffer capacity*. Buffers are defined as substances which by their presence in solution increase the amount of acid or alkali that must be added to cause a unit *p*H change. In other words, buffers prevent wide fluctuations in *p*H even though acids or alkalis are added. The most efficient buffers are mixtures of weak acids or weak bases with their corresponding salts. It is thought that the buffering action of apple juice is mostly due to malic acid and its salts.[64]

In a study of Lane's Prince Albert apples growing on different *rootstocks* there seemed to be little difference in the *p*H of the juices of the fruits although there was a suggestion that fruit from the less vigorous rootstocks (II and IX) had less acid juice. There was also a suggestion of less total acidity in the juice from a strongly dwarfing rootstock like Malling IX than that in apples grown on a vigorously growing stock like I.[66]

The *leaf–fruit ratio* has an effect on total acidity of apples. In a study of Ben Davis and Delicious apples it was shown that acidity increased as the number of leaves per fruit increased (see Fig. 10).[67] This would indicate that acidity depends in part on or is correlated with ample carbohydrate manufacture by the leaves. This observation is further substantiated by the fact that acidity was high in apples in years when climatic conditions were favorable for carbohydrate accumulation in the fruits.

Apples grown in clean cultivation have been found to have a somewhat lower acid content than similar apples grown in *sod*. *Nitrogen fertilization* of the trees growing in sod seemed to result in some-

[66] J. W. Brown, *Ann. Botany, 40,* 129 (1926).
[67] M. H. Haller and J. R. Magness, *Proc. Am. Soc. Hort. Sci., 22,* 189 (1926).

what lower fruit acidity.[68] In both of these cases the trees responded to nitrogen fertilization in other ways than just acidity content. Hence it cannot be assumed that trees growing at a high nitrogen level would necessarily show this response to nitrogen additions to the soil.

Ringing of apple tree limbs has been found to increase the total acids in apple fruits.[69]

D. Nitrogen Compounds

The nitrogen compounds are of interest because they are such an important constituent of the protoplasm of the cells. The full significance of these nitrogen compounds in either the physiology of the fruit or its technology is not yet known. Certainly the nitrogen compounds are not of any great significance in apples from the human nutrition standpoint (*i.e.*, protein contribution).

In most of the investigational work that has been done just the *total nitrogen* has been determined. However, in some of the work this total nitrogen has been fractionated. The protein nitrogen is usually expressed as the alcohol-insoluble nitrogen and the nonprotein fraction as soluble nitrogen.

1. NITROGEN

In general, the absolute amount of total nitrogen in apple fruits increases as the fruits develop on the tree. When expressed as grams of nitrogen per fruit, the increase in Stayman Winesap was about 100% during fruit development in an Ohio study.[70] This study stopped at about the first of September and there may have been a decrease before actual harvest. In an English study it was shown that the total nitrogen per fruit increased rapidly until 130–140 days after full bloom and then a slight decrease was evident.[71] Another English study showed that nitrogen moved into the young fruits very rapidly during the first six weeks after bloom and then there was a slight decrease in total amount.[72]

[68] T. W. Wallace, *Univ. Bristol Agr. Hort. Research Sta. (Long Ashton) Spec. Rept.*, 1930.
[69] M. Onslow, F. Kidd, and C. West, *Rept. Food Inv. Board, 1932*, 70 (1933).
[70] J. H. Gourley and E. F. Hopkins, *Ohio Agr. Expt. Sta. Bull.*, 470, 1931.
[71] A. C. Hulme, *Biochem. J., 30*, 258 (1936).
[72] D. Haynes and H. K. Archbold, *Rept Food Inv. Board, 1929*, 106 (1930).

The percentage of total nitrogen in Stayman Winesap apples has been shown to decrease on a fresh weight basis from July to the first of September.[70] This same percentage decrease has been shown to exist in other studies.[72,73]

2. PROTEIN NITROGEN

Not much is known about the nature of the proteins in apple tissue. However, it has been reported that apple protein is very "complex and unusual" in nature. It is thought that tyrosine, arginine, and tryptophan are among the hydrolytic products.[74,74a]

The protein nitrogen in apple pulp has been found to increase steadily until 130 days from full bloom. The protein nitrogen in the apple peel was found to increase very slightly for 180 days following full bloom.[72]

3. SOLUBLE NITROGEN

Among the soluble nitrogen fractions are the amino acids, the amides, ammonia nitrogen, and basic nitrogen. The amount of basic amino acids (arginine, histidine, and lysine) present in the apple in the free state is very small.[75] There seems to be a relatively large proportion of free amide nitrogen in the apple. Assuming all the amide

TABLE 11. Percentage of Total Nitrogen Contributed by Various Fractions in Alcoholic Extract of Bramley Seedling in a One-Liter Extract[75]

Nitrogen fraction	Amount, mg.	Contribution to total N of extract, %
Total	590	—
Ammonia	37	6.3
Amide	146	24.8
Amino	267	45.3
Basic	21	3.6
Rest	119	20.0

to be asparagine, this amide would account for 50% of the soluble nitrogen present in mature fruits. It is not known that asparagine is the only amide present in apples, but it is known that glutamine is absent. Some preliminary work has suggested that the apple does not

[73] H. O. Askew, *J. Pomol. Hort. Sci., 13,* 232 (1935).
[74] A. C. Hulme, *Rept. Food Inv. Board, 1938,* 125 (1939).
[74a] A. C. Hulme, *Nature, 158,* 58 (1946).
[75] A. C. Hulme, *Rept. Food Inv. Board, 1937,* 117 (1938).

contain very large amounts of proteoses or polypeptides and that the small amounts present are of the same order of magnitude in both young and mature fruits.[75] Table 11 includes an analysis of the alcohol-soluble fractions of one variety of apples.

The soluble nitrogen in apples (as per cent of total nitrogen) has been shown to increase in English apples until 130 days after full bloom and then there is a slight decrease.[76]

4. EFFECT OF ENVIRONMENT AND CULTURE ON NITROGEN COMPOUNDS

Soil. Work done on Bramley Seedling apples in England indicated that soil type may have some influence on the nitrogen content of the fruit. The lowest amount of nitrogen was found in fruit growing on a silt soil while the highest amount was found in fruit from alluvial gravel or chalk.[77] One must remember here that soil type alone may not be responsible for these differences. Soil treatment or method of culture might outweigh by far any differences due to type alone. Differences in nitrogen levels in the soils must be considered also. Ordinarily one would expect more leaching of nitrates in a gravelly or sandy soil and hence possibly less nitrogen in the fruit in that type of soil.

Rootstock. Work done on Lane's Prince Albert apples grown in England shows some differences in nitrogen content as a result of rootstock type.[77] For example, in 1924 there was 0.081% total nitrogen in apples growing on Malling I whereas, there was 1.008 in fruits grown on II and 0.049% in fruits on X. There seemed to be little relation in this study between the vigor of the rootstock and the amount of nitrogen in the fruit. *Seasonal* differences were larger than differences due to rootstocks.

Soil Management. The effect of nitrogen additions to the soil on the amount of total nitrogen present in the fruit doubtless depends in large part on the level of this element in the soil before treatment. In some studies[78,79] nitrogen additions to the soil have not increased the nitrogen content of apple fruits. This lack of response may well have been due to the fact that the trees were already growing at a high nitrogen level. Other studies[70,80] have shown a response in nitrogen

[76] A. C. Hulme, *ibid., 1936,* 126 (1937).
[77] J. W. Brown, *Ann. Botany, 40,* 129 (1926).
[78] W. W. Aldrich, *Maryland Agr. Expt. Sta. Bull., 326,* 1931.
[79] J. L. St. John, E. L. Overholser, and F. L. Overley, *Plant Physiol., 17,* 435 (1942).
[80] T. W. Wallace, *Univ. Bristol Agr. Hort. Research Sta. Rept.* 1930.

level in the fruit from additions of nitrogen to the soil. The effect of nitrogen additions has been more marked in this connection with sod culture than with clean cultivation.[80]

Clean cultivation (without nitrogen additions) has been shown to result in high fruit nitrogen contents.[80] This effect would be expected to occur only while the natural organic level in the soil was relatively high. Clean cultivation might be expected eventually to result in a considerable depletion of the nitrogen reserves in the soil and hence possibly a reduced amount of nitrogen in the fruit.

Ringing. Ringing of limbs of apple trees in early summer has been found to reduce the nitrogen content of apple fruits by harvest time.[81]

E. Mineral Constituents

Minerals are requisite for normal plant tissue metabolism. They are of interest from the human nutritional point of view. The minerals form basic salts with the weak acids in the apple flesh. These basic

TABLE 11A. Percentages of Mineral Elements in Edible Portion of "Apples"[a]

Ca	Mg	K	Na	P	Cl	S	Fe	Cu	Mn
0.007	0.006	0.116	0.01	0.01	0.004	0.005	0.0003	0.000071	0.000084

[a] H. C. Sherman, *Chemistry of Food and Nutrition.* 7th ed., Macmillan, New York, 1946, p. 96.

salts are known to be of value in human nutrition. The exact form in which these minerals exist in the flesh of the apple is not known (Table 11A).

The total or absolute amount of minerals in the apple flesh increases for something like 120 days after full bloom.[82] Due to the increase in size and increase in soluble organic solids of the fruits, the percentage of minerals shows a decline in percentage on both a dry and fresh weight basis.[83]

Potassium. This element constitutes the main portion of the ash or mineral content of apple tissues.[83] It is usually more than 40% of the total ash of Ohio grown apples. The K content (as K_2O) of Lane's Prince Albert apples in England has been reported to be

[81] M. Onslow, F. Kidd, and C. West, *Rept. Food Inv. Board, 1932,* 70 (1933).
[82] J. W. Brown, *Ann. Botany, 40,* 129 (1926).
[83] E. F. Hopkins and J. H. Gourley, *Ohio Agr. Expt. Sta. Bull.,* 519, 1933.

0.11% of the fresh weight.[83a] Although the total amount of potassium in apples increases as they mature on the tree, the actual percentage of the fresh weight decreases (Fig. 14).

Phosphorus. The P content (as P_2O_5) of Lane's Prince Albert apples grown in England was reported as 0.029% of the fresh weight.[83a] While the total amount of phosphorus in apples increases in each fruit, the percentage of this element in the fresh weight de-

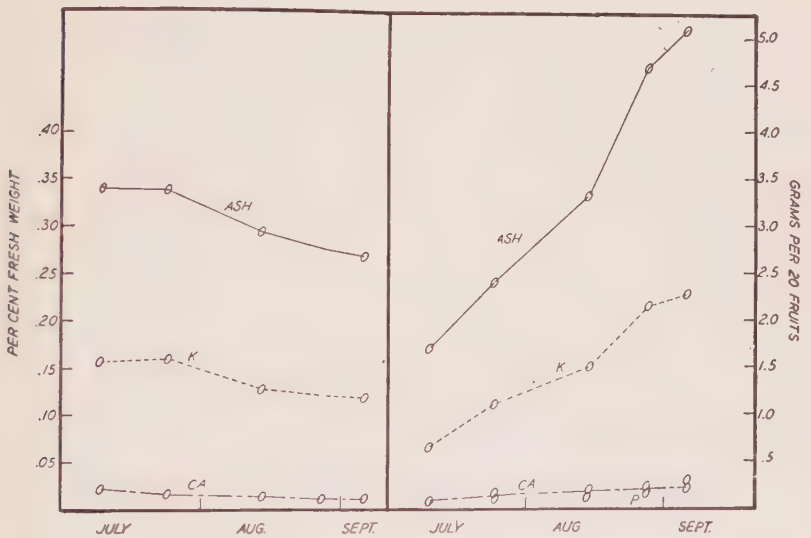


Fig. 14. Changes in the total ash, potassium, and calcium contents of Stayman Winesap apples during the growing season on a fresh weight basis (left) and on an absolute basis (right).[83]

clines slightly during the course of the growing season.[83] In McIntosh apples the insoluble phosphorus fraction (insoluble in 5% trichloracetic acid) has been found to decline very markedly in percentage of fresh weight during the growing season.[83b]

Calcium. Analyses of Baldwin apples in New York state showed from 0.0056 to 0.0067% of the fresh weight as calcium. McIntosh apples ranged from 0.0069 to 0.0095% calcium. Rhode Island Greenings had from 0.0072 to 0.0088% calcium. There was some range in calcium content within a variety from season to

[83a] J. W. Brown, *Ann. Botany, 40,* 129 (1926).
[83b] G. Krotkov and V. Helson, *Can. J. Research, 24,* 126 (1946).

season.[83c] The total amount of calcium increased slightly during the growing season in each fruit but on a percentage basis it was found to decrease slightly.[83]

Iron. The Fe content (as Fe_2O_3) of Lane's Prince Albert apples was found to be 0.00046% of the fresh weight.[83a] While the absolute amount of iron increased in the developing fruit, the percentage remained fairly constant during the growing season.[83]

Magnesium. The Mg content (as MgO) of Lane's Prince Albert apples has been reported to be 0.0071% of the fresh weight.[83a]

Manganese. Only traces of this element are found in apples and there seemed to be little difference in the amount at two different sampling dates during the growing season.[83]

Sodium. The sodium content of Ohio grown Nonpareil apples was found to be 5% of the total ash.[83]

Boron. The boron content of Golden Russet apples at petal fall was reported to be 0.00087 mg. per apple and 0.0005% of the dry weight. The content at harvest time was 0.043 mg. per apple and 0.0002% of the dry weight.[84] This indicates that while the absolute amount per apple was increasing during the growing season, the percentage was decreasing.

Copper. It has been found that the copper content of "apples" was about 0.0001% of the fresh weight.[85]

Sulfur. The sulfur content (expressed as SO_3) of apple tissue has been reported to be about 4.6% of the ash of one variety.[86]

Zinc. The zinc content of "apples" has been reported to be about 0.00015% of the fresh weight.[86a]

Aluminum. The aluminum content of "apples" has been found to be about 0.0005% of the fresh weight.[86b]

Iodine. Traces of iodine have been found in apple tissue.[86c]

[83c] Z. I. Kertesz, *private correspondence*, 1948.
[84] J. C. Johnson and W. A. DeLong, *Plant Physiol., 12,* 219 (1937).
[85] B. Guerithault, *Thèse Pharm. Sup. Paris*, 1927; *Chem. Abstracts, 22,* 809 (1928).
[86] W. D. Bigelow, *U. S. D. A. Bur. Chem. Bull., 66,* 1905.
[86a] G. Bertrand and B. Benzon, *Bull. Soc. Hyg. Alliment, 16,* 457 (1928); *Chem. Abstracts, 23,* 2505 (1929).
[86b] F. P. Underhill, F. I. Peterman, E. G. Gross, and A. C. Krause, *Am. J. Physiol., 90,* 72 (1929).
[86c] J. F. McClendon and J. C. Hathaway, *Proc. Soc. Exptl. Biol. Med., 21,* 129 (1923).

Applesauce made from Ohio grown apples was shown to have 0.0000125% of iodine whereas dried apples from the Oregon goitrous region contained only 0.0000003%.[86d]

Effect of Soil. Studies on the effect of soil on the ash content of apples have been made in England.[86e] Since the soils occurred in different areas it is not always clear in these studies whether the differences noted were due to soil alone. Nevertheless this study did

TABLE 12. EFFECT OF SOIL ON MINERAL CONSTITUTION OF BRAMLEY SEEDLING APPLES[86e]

Soil type	Dry wt., %	Per cent of fresh weight					
		Ash, %	K_2O, %	P_2O_5, %	Fe_2O_3, %	CaO, %	MgO, %
Alluvial gravel	11.26	0.224	0.1198	0.0243	—	0.0052	0.0037
Silt	11.10	0.220	0.1219	0.0204	—	0.0048	0.0046
Chalk	13.19	0.229	0.1112	0.0166	—	0.0042	0.0050

TABLE 13. EFFECT OF ROOTSTOCK AND SEASON ON MINERAL CONSTITUTION OF LANE'S PRINCE ALBERT APPLES[86e]

Year	Malling rootstock No.	Dry wt., %	Ash, %	K_2O, %	P_2O_5, %	Fe_2O_3, %	CaO, %	MgO, %
1923	I	12.96	0.179	0.0976	0.024	—	0.0042	0.0068
1924	I	10.95	0.183	0.0983	0.023	0.00046	0.0036	0.0068
1924	II	10.87	0.209	0.110	0.029	0.00060	0.0031	0.0071
1923	IX	11.50	0.159	0.088	0.023	—	0.0037	0.0058
1924	IX	11.48	0.154	0.081	0.024	0.0062	0.0032	0.0061
1923	X	12.88	0.188	0.1016	0.025	—	0.0039	—

indicate that the ash content may vary in apples from location to location. It was reported in this English study that apples grown on gravelly and silty soils had a high total ash content with high potassium values. Fine silty soils were found to produce low values for total ash, potassium, and phosphorus. These soils may have differed in other respects than just soil type. For example, the available mineral content, the *p*H, and water content of the soils may have been important factors responsible for the ash variations in the apples grown on these different soils (Table 12).

[86d] American Can Co. Research Dept., *The Canned Food Reference Manual*, 2nd ed., American Can Co., New York, 1943.
[86e] J. W. Brown, *Ann. Botany, 40*, 129 (1926).

Effect of Season. As might be expected the ash content of apples may vary from season to season. Variations in rainfall and possibly soil temperature would be typical climatic factors that might vary enough from season to season to affect the ash content of apple fruits. Seasonal variations may be seen in Table 13.

Effect of Rootstock. An English study has shown that the ash content of Lane's Prince Albert apples varies somewhat depending upon the rootstock upon which this variety is grown.[86e] Table 13 indicates that fruits from trees growing on Malling II had a higher ash content than fruits from the other stocks. Fruits from trees on Malling IX had a rather low ash content.

Effect of Variety. In a study of the ash content of several Ohio apple varieties no significant differences were found that could be attributed directly to the variety factor,[83] except for McIntosh. This variety was found to be very low in total ash and calcium but high in phosphorus.

Effect of Fruit Color. In an English study it was found that a higher percentage of ash was present in red apples than in green ones in one variety investigated.[86e] In an American study this association of high coloration with high ash content was not found in Baldwin.[86] Hence, it would seem that the correlation of ash content with fruit color is not clear cut in the light of present knowledge.

Effect of Soil Fertilization. When potassium additions are made to the soil the potassium percentage of the ash is often increased.[83] Sometimes this potassium increase is accompanied by decreases in phosphorus, calcium, and magnesium.

F. Fats, Oils, and Waxes

Fats are defined as esters of glycerol and organic acids with four or more carbon atoms. Generally speaking, if members of the vegetable fats are liquid at room temperature they are spoken of as oils. If they are solid they are called fats. The "essential oils" are the plant oils which are fragrant, volatile constituents. The waxes are fatlike substances which are defined as mixtures of higher alcohols with esters of these same alcohols and the fatty acids.

It is not clear from a study of the analytical work done with apples whether gross analyses of the tissues refer only to the true fats

since crude ether extracts were made which contained all the ether-soluble components. Where specific work has been done on the fatlike substances they will be dealt with separately under "essential oils" and "waxes."

Fats. The total amounts of true fats in the apple flesh are not very significant. There is considerable fat in the seeds of the apple (see chapter X). Certainly there is not enough fat in the flesh of the apple to be of significance from the human nutritional standpoint. Some of the oils and waxes are of importance from the standpoint of fruit physiology and these will be discussed in relation to certain physiological processes. The essential oils are of importance because of the aroma they impart to apples although they are not the only chemical fraction contributing to the odor of this fruit.

The content of fat in a number of apple varieties that have been analyzed ranges between 0.3 and 0.4% of the fresh weight.[87] No data have been presented to show the changes that take place in this constituent during the course of the growing season.

Cutin and Waxes. Apples have a firm, thick cuticle covering the epidermis of most varieties. It has already been pointed out that the thickness of this cuticle varies from variety to variety. If the cuticle is separated from adjacent tissues and is then extracted with ether, it may then be separated into two main portions, the "ether-soluble fraction" and the "ether-insoluble fraction."[88,89,89a] The former consists of a mixture of normal paraffin hydrocarbons, primary and secondary alcohols and ursolic acid. The latter fraction is referred to frequently as the *cutin.* Knowledge of the chemical nature of apple cutin is meager but by comparison with the cutin of certain other plants it might be assumed to be an esterlike substance, which on saponification yields a number of incompletely identified solids and semiliquid acids.[88]

The amount of cutin (insoluble fraction) has been found to be greater at maturity than during the early stages of growth. The proportion of total ether extract to cutin varies considerably from variety

[87] C. Chatfield and C. I. McLaughlin, *U. S. D. A. Circ.,* 50, 1931.
[88] K. S. Markley and C. E. Sando, *J. Agr. Research, 46,* 403 (1933).
[89] K. S. Markley, S. B. Hendricks, and C. E. Sando, *J. Biol. Chem., 97,* 103 (1932).
[89a] A.C. Chibnall, S. H. Piper, A. Pollard, J. A. B. Smith, and E. F. Williams, *Biochem. J., 25,* 2095 (1931).

to variety but the ratio is about 44 to 56, indicating that the cuticle of apples is composed of approximately 44% of ether-soluble constituents and 56% of ether-insoluble material (cutin).[89]

The low melting portion of the waxy constituents of the apple has been shown to be a green "lardaceous" mass which becomes semi-liquid when rubbed between the fingers. The bulk of this portion has been shown to consist of *n*-nonacosane with a melting point of 149°F. (65.1°C.) and a much smaller quantity of the alcohol 10-nonacosanol with a melting point of 177.8°F. (81°C.).[89,89a] In an English study it was found that the wax constituents of the cuticle contained—*n*-nonacosane, *n*-heptacosane, D-10-nonacosanol, *n*-triacontanol, *n*-octacosanol, and *n*-hexacosanol.[89b]

The waxlike constituents on the surface of the apples are composed of ursolic acid ($C_{30}H_{48}O_3$), oily fraction, and total ether extract. The oily fraction increases at a faster rate than ursolic acid during growth. This explains the progressive increase in the percentage of oily fraction in the total ether extract with advancing maturity. A change in the physical properties of the natural waxy coating undoubtedly accompanies the shift in the ratio of oily fraction to ursolic acid. Such a change may affect the permeability of the waxy layer to gaseous diffusion and the adhesion of spray materials.[88,90,91]

Factors Affecting Waxes. Not much study has been made of this point but it has been shown that in general there was more ursolic acid and total ether extract on the *shady side* than on the sun-exposed side of the fruit. There was little difference in the oily fraction from one side of the fruit to the other. Amounts of all three fractions have been shown to vary from *variety to variety* and from *season to season*.[88,90]

Essential Oils. Geraniol has been found to be one of the essential oils present in apple tissue.[92]

G. Astringent Materials

The astringent materials in fruits contribute the characteristic quality of many unripe fruits which makes one's mouth "pucker up."

[89b] A. C. Chibnall, S. H. Piper, A. Pollard, J. A. B. Smith, and E. F. Williams, *Biochem. J., 25,* 2095 (1931).
[90] K. S. Markley and C. E. Sando, *J. Agr. Research, 42,* 705 (1931).
[91] A. C. Hulme, *Rept. Food Inv. Board, 1937,* 123 (1938).
[92] F. B. Power and V. K. Chesnut, *J. Am. Chem. Soc., 44,* 2938 (1922).

A green, unripe apple when eaten makes the linings of the cheek and tongue feel as though they were being desiccated.

The term "total astringents" is a broadly inclusive one embracing all substances which will reduce potassium permanganate under definite controlled conditions. True tannins, tannin derivatives, some coloring materials (flavones), and other substances are included under this broad term.[93] Tannins may be hydrolyzed by acids into a variety of products, one being nearly always a sugar and the other a hydroxy derivative of aromatic series, usually an acid. Sometimes a phenol is

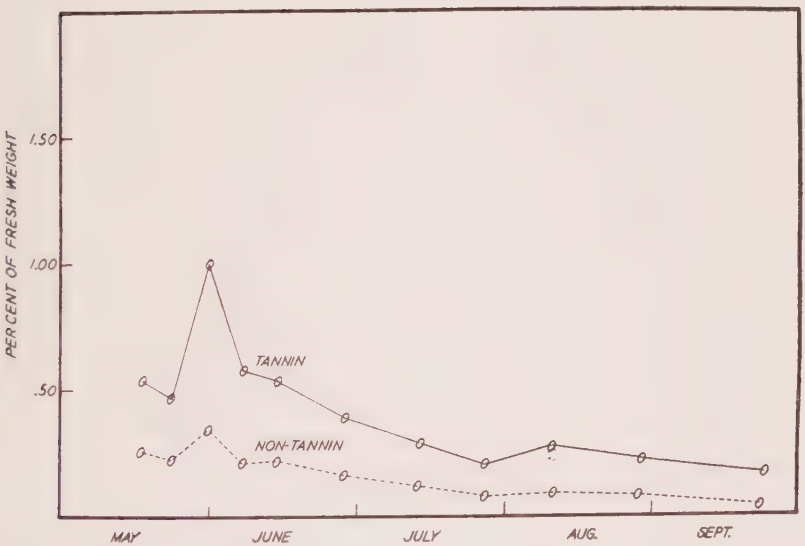


Fig. 15. Changes in the tannin and nontannin astringent materials in Baldwin apples during the growing season.[93a]

produced instead of a sugar. Tannin in apples is thought to be of the pyrocatechol type.[94] The tannins seem to act as a chromogen for oxidase enzymes. When a green apple is sliced and exposed to air it quickly darkens due to the oxidation of tannin compounds. As the apples ripen and the tannin quantities diminish the darkening becomes less upon exposure to air. Tannin is well distributed throughout the

[93] J. S. Caldwell, *J. Agr. Research, 36,* 291 (1928).
[93a] J. S. Caldwell, *U. S. D. A. Tech. Bull.*, 403 (1934.)
[94] R. W. Thatcher, *ibid., 5,* 103 (1913).

flesh of the apple of most varieties but most of it in the Yellow Newtown apple is in the epidermis.[95]

The astringent materials play an important part in determining the eating quality of apples. The relative proportion of sugars, acids, and astringents (*i.e.*, relative astringency) is probably one of the most important factors in determining eating quality.

The percentage of astringent materials in apples gradually declines as the fruits mature on the tree; this is doubtless due to dilution by other materials. At harvest time a variety like Rhode Island Greening may have as much as 0.06% of astringent materials on a fresh-weight basis.[96] See Figure 15.

Factors Affecting Astringent Materials. Varieties of apples differ widely in their amount of astringent materials. One study lists the astringency of 216 varieties over a period of from three to five years. The Hyslop crab apple in a given year had a total astringent content of 0.328% whereas McIntosh had 0.096% on a fresh-weight basis at harvest time.[93] This is understandable when one remembers how astringent the crab apples are.

There are *seasonal* variations in the tannin content of a given variety although total astringency does not vary to any great degree. The tannin fraction has been found to vary as much as 100% within a given variety grown in the same location from *year to year*. The tannin and nontannin fractions seem to vary independently from year to year within a given variety.[93]

On an absolute basis the *relative astringency* varies a great deal more from year to year than does total astringency. This is true because the former depends upon the amounts of sugars and acids present in apples and these vary widely from year to year.[93] Seasons that produce apples with a high sugar content in apple fruits tend to depress the relative astringency to a low level. Conversely, the seasons which result in low sugar content in the fruit may result in a high relative astringency.[93]

A deficiency in *rainfall* in one season did not seem markedly to affect the total astringency of apples although it did affect the relative astringency through its effect on sugars.[93]

[95] E. L. Overholser and W. V. Cruess, *Calif. Agr. Expt. Sta. Tech. Paper*, 7, 1923.

[96] W. D. Bigelow, H. C. Gore, and B. J. Howard, *U. S. D. A. Bur. Chem. Bull.*, 94, 1905.

H. Color Compounds

1. GREEN AND YELLOW PIGMENTS

Young apple fruits are all green. As the fruits mature on the tree the fruits become yellow or red (or both). Whether the green coloration of the apple skin is due to the same type of chlorophyll found in the leaves is not known. At any rate some type of chlorophyll is presumably responsible for this green. Chlorophyll (as in leaves) is found in the form of chloroplasts or plastids (*i.e.*, small colored bodies) within the cells of the fruit skin. The flesh as well as the skin of immature fruits is often greenish white or green. Whether this green is due to chlorophyll is not known, but it presumably is.

As apples ripen on the tree the green gradually fades out and yellow appears. While some varieties are picked while the skin is still very green (Rhode Island Greening, for example) most apples are not harvested until there is some development of yellow. This yellow coloration of apples is called the *ground* or underlying color. The overlying red color is called the *surface* color. Some varieties likes Grimes Golden and Golden Delicious usually do not have any surface color except for an occasional red blush. On the other hand, some varieties highly colored with red do not have any ground color when harvested.

It is known that the yellow coloration of leaves is due to xanthophylls or carotenoids or both and it has often been presumed that these were responsible for the yellow in apples. Actual chemical study has shown that in one yellow variety at least the yellow coloration was wholly or in part due to the presence of a flavone glycoside called 3-galactosidylquercetin. This pigment was also found in red-colored apples and may be the chemical responsible for all of the underlying ground color of the red varieties as well as the yellow ones.[97]

Factors Affecting Ground Color. Ground color development may be influenced in several ways while the fruit is still on the tree or after harvest. One factor which affects ground color is the *leaf–fruit ratio*. A fully developed ground color in a variety like Grimes Golden and Jonathan at harvest time requires at least 30 leaves per fruit. Fewer leaves per fruit resulted in a greenish ground color at harvest time.[98] More than 40 leaves per fruit did not result in any additional development of ground color in most of the varieties studied.

[97] C. E. Sando, *J. Biol. Chem., 117,* 45 (1937).
[98] M. H. Haller and J. R. Magness, *Proc. Am. Soc. Hort. Sci., 22,* 189 (1925).

The use of thiocyanate sprays in the orchard has seemed to result in a premature development of ground color in apples.[99]

When some fruits are picked in a green or immature condition they are sometimes ripened with *ethylene*. Exposure to ethylene will cause an accelerated loss of the green and development of the yellow in apples although this treatment is not often used with this fruit.[100] Ethylene treatments are often called a "bleaching" process because of the rapid disappearance of the green coloration. This treatment should more properly be called a ripening process since there is no actual bleaching of the fruit.

2. RED COLORATION

Red coloration in apples is due to the presence of anthocyanins.[97,99] The anthocyanins are complex chemical compounds which are in solution in the plant sap. They have benzopyrilium rings and occur as glycosides.[100a] In the apple these compounds are confined to the skin in most varieties. Most of the anthocyanins are found in the hypodermis with some in the epidermis. In some varieties of apples there is some red coloration in the flesh of the fruit also. This coloration is presumably also due to the anthocyanins. It would seem obvious that the anthocyanins are in solution because in some varieties the red coloration of the skin will leach out of the skin and appear in the flesh in overripe fruits. This is often seen in overmature Wealthy apples which are left on the tree too long.

The anthocyanins act as an indicator or dye in the sap or cell contents of the apple skin, that is, they are sensitive to *p*H. When a red apple is exposed for a few minutes to vapors of ammonia the skin will turn purple and finally black. If the exposure is not too long and the cells are not killed by the ammonia, the red may reappear. In other words, the apple anthocyanins are red in an acid medium and blue or purplish black in an alkaline medium.

The precursor of the anthocyanins is formed in the leaves of some plants and moves into the fruits.[101] Whether this is true in the apple is not known. Certainly most of the sugars which are components of anthocyanins are manufactured in the leaves.

[99] R. B. Dustman and I. J. Duncan, *J. Am. Chem. Soc.*, *58*, 1511 (1936).
[100] F. W. Allen, *Hilgardia*, *6*, 381 (1932).
[100a] K. P. Link, in H. G. Gilman, ed., *Organic Chemistry Vol. II*. 2nd ed., Wiley, New York, 1943.
[101] M. W. Onslow, *The Anthocyanins Pigments of Plants*. Cambridge Univ. Press, London, 1925.

Two sets of workers have found that the red coloration in apples was an anthocyanin called "idaein." This compound is classed as a glycoside which on hydrolysis yields cyanidin and galactose. Another name for idaein is 3-β-galactosidylcyanidin. It is presumed to be present in all red varieties of apples.[97,102]

Anthocyanin development is thought to be only a function of living cells. When the cells are killed certainly the red coloration does not develop.[103] All the steps involved in anthocyanin development in apples have not yet been studied. It is known that sugars are requisite for the formation of the red coloration.

The role which anthocyanins may play in apple physiology is not known. A number of speculations have been made in this connection, however.[101] One concerns itself with the fact that fruit temperatures are raised when there is exposure to the sun (through absorption of heat rays) and hence transpiration rate is increased. This speculation implied that transpiration is a useful process and has teliological implications. Another speculation is that the anthocyanins are respiratory pigments which act as oxygen carriers. It should be remembered here that many apples do not have any anthocyanins.

Factors Affecting Anthocyanin Development. It has already been pointed out that *sugars* are requisite for the formation of anthocyanins. This means that photosynthesis must be adequate to produce sufficient sugars not only for growth of all the tree parts and for fruit bud differentiation, but also for the development of this pigment. Hence, one of the primary factors affecting red coloration is the proper number of *leaves per fruit.* Fruit must be properly thinned while on the tree so that there is an adequate leaf–fruit ratio. Most varieties of apples which normally are red require from 30 to 50 leaves per fruit to develop a full complement of anthocyanins.[98]

An adequate supply of *water* seems essential for the production of anthocyanins in apples.[104] This effect may be in part indirect, that is, water is needed for photosynthesis and hence for anthocyanin production. On the other hand, the effect may be partly a direct one. In seasons of drought there is not a full development of red coloration on apples. The apples may be reddish, yet not a bright or brilliant red. This coloration is sometimes called a "dirty red."

Apples unlike some fruit require *light* for the development of

[102] R. B. Dustman and I. J. Duncan, *Plant Physiol., 15,* 343 (1940).
[103] J. M. Arthur, *Am. J. Botany, 18,* 896 (1931).
[104] J. R. Magness, *Proc. Am. Soc. Hort. Sci., 25,* 289 (1928).

anthocyanins.[105,106] This, of course, is in addition to the light needed for photosynthesis. Light quality plays an important part in determining the amount and shade of red developing on apples. The ultraviolet part of the spectrum (3600–4500 Angstrom units) seems to be essential for the anthocyanins in apples.[107] Apple fruits must first have a certain degree of maturity on the tree before exposure to light will induce red color formation. It would seem that a certain chromogen (forerunner of color formation) must be present before light will induce anthocyanin development.[104] The fruit grower can influence the light reaching his fruit in some ways. Proper *spacing* of trees in the orchards will prevent undue shading of one tree by another. Good pruning practices open up the trees so that fruit coloration is somewhat better than in unpruned trees. Thinning of fruits may have some effect here in allowing more light to strike the fruits left on the tree, although the major effect of thinning on color is undoubtedly in lessening the competition for carbohydrates.

Temperature has a considerable effect both directly and indirectly on color formation in the apple fruit. Temperatures must be adequate for photosynthesis during the growing season so that the requisite amount of sugars can be formed. In addition to this indirect effect there is a more direct one. Unless there are extended periods of rather low temperatures during the latter part of the ripening period red color will not develop in apple fruits. The ideal weather situation for good color formation is characterized by warm days (for maximum photosynthesis) and cool nights during the latter part of the ripening season.[104,108] Just why relatively low temperatures are required for this conversion of sugars into anthocyanins is not known. It may be that the reduced respiration accompanying the low temperature allows sugars to accumulate. It is often said that "frost" is required for good red coloration. It should be noted that it is not frost as such but the temperatures that prevail. In other words the temperature need not drop down actually to 32° F. to get full red coloration development.

It has been reported that *thiocyanate sprays* would accelerate the development of anthocyanins. Calcium or sodium thiocyanate sprays have been used with this idea in mind.[99,102] Use of such sprays will even cause a variety like Rhode Island Greening to develop a considerable red blush. These sprays are unfortunately accompanied by

[105] E. L. Overholser, *ibid., 14,* 73 (1917).
[106] A. L. Schrader and P. C. Marth, *ibid., 28,* 552 (1931).
[107] L. R. Streeter and G. W. Pearce, *ibid., 28,* 49 (1932).
[108] S. W. Fletcher, *Maryland Agr. Expt. Sta. Bull.,* 353, 1933.

marked chlorosis and even death of the tree's leaves and hence have not been adopted commercially. This effect of the thiocyanates has been explained as being due to destruction of chlorophyll. Following this chlorophyll destruction there seemed to be more infiltration of ultraviolet light to the hypodermal layers of the layers of the fruit skin and hence more red color development.[109]

Attempts have been made to induce red color formation in apples by the use of *sugar applications* to the soil.[108] While these attempts were partially successful it is not clear why they worked. It is not known whether the sugar actually entered the tree and functioned directly as a source of anthocyanin base material. It is more likely that the sugar application merely resulted in a temporary check on the intake of nitrogen of the soil by the tree. Such additions of sugars are known to cause rapid multiplication of certain soil bacteria. In their growth these bacteria deplete soil nitrogen. Low nitrogen levels are known to have an effect on red coloration as indicated later. This method of increasing fruit coloration does not seem to have any practical implications.

It is a well-demonstrated fact that the use of *nitrogen* fertilizers tends to lessen the development of anthocyanins in apples.[110,111] The exact effect of the nitrogen addition, of course, depends in large part on the nitrogen nutritional level of the tree involved. For example, if the tree is already at a high nitrogen level, further additions of nitrogen fertilizer may have no detrimental effect on fruit color. There may be several reasons for this effect of nitrogen fertilizers on the development of anthocyanin. One is that fertilization results in increased shoot and leaf growth. This growth may deplete carbohydrates enough so that there are not enough left for best anthocyanin development. Then, too, in a high nitrogen level tree with its extensive leaf and shoot growth there tends to be more shading of the fruit (exclusion of ultraviolet).

The use of certain *hormone* sprays to delay dropping of the fruits in the harvesting period is practiced to allow more complete development of red coloration. Many varieties tend to drop their fruits before they are fully colored. Sprays of α-naphthaleneacetic acid or the amide of this acid are used commercially to delay abscission and allow fuller development of the anthocyanins.[112]

[109] M. W. Reger, *Proc. Am. Soc. Hort. Sci., 45,* 111 (1944).
[110] D. Boynton and J. C. Cain, *ibid., 40,* 19 (1941).
[111] J. R. Magness, L. P. Batjer, and L. O. Regimbal, *ibid., 37,* 39 (1940).
[112] M. B. Hoffman, *Cornell Univ. Agr. Expt. Sta. Bull.,* 766, 1941.

Attempts are sometimes made at enhancing color formation of apples during the postharvest period. It has already been pointed out that ethylene gas cannot be used for this purpose. This gas merely stimulates the normal ripening processes and induces the normal green-to-yellow change in ground color. It is true that such ripening processes may seem to result in a slight increase in red coloration, that is, fruits before treatment may have no apparent red coloration and yet have a few streaks of red after treatment. This would seem to be due to the fact that the red was already there before treatment but was masked by the dark green. Occasionally apples are harvested and then placed under the tree to develop more red. They are placed under the tree to escape infrared radiation from the sun and subsequent heat injury. They are exposed to enough ultraviolet to develop some red on the exposed side of the fruits during a week or ten days. Sometimes the apples are turned after a week so that both sides will become red. This process is called "sun coloring."[113] Such apples must be marketed rather quickly since they ripen rather rapidly during the coloring period. Light treatments do not affect the red color formation after the apples have been stored for several months.[104]

Local injuries to the fruit while it is maturing on the tree are likely to induce red color formation around the injured areas. Certain types of insect and disease damage will often result in highly colored spots on the fruit.

When apples are treated with high concentrations of *methyl bromide* after harvest there is often an increase in red coloration. This effect is not as striking on apples as it is on peaches.[114] As yet this process has no commercial application because it makes the fruit off-flavored. It may be purely an injury effect.

I. Enzymes

Enzymes are often defined as "organic catalysts." As far as is now known enzymes are produced only by living protoplasm. They may function, however, without being in contact with living cells, that is, plant enzymes may be extracted from the living tissue and still function. Enzymes when acting as catalysts can influence the rate of a given chemical reaction and in some cases may even initiate such re-

[113] M. B. Hoffman, *Proc. Am. Soc. Hort. Sci., 35,* 212 (1938).
[114] L. L. Claypool, *ibid., 38,* 289 (1941).

actions. Cells of some plants may lack specific enzymes in their active forms but may contain chemical precursors of the enzymes which under certain conditions may be converted into the enzymes. Such materials are called *zymogens*.[115] Some chemical substances are known to activate or accelerate enzyme activity. These materials are known as *coenzymes*.

The enzyme systems of the apple have not been very completely studied, but the information that is available is summarized in the following paragraphs.

1. DIASTASE

Diastase is the enzyme which causes the hydrolysis of starch to maltose—with dextrins as probable intermediate products of the reaction. Starch is known to be a constituent of apple tissue (particularly in immature fruit) so one would naturally wonder if diastase were present in the apple fruit. Diastase has been found to exist in apple tissue as the fruit ripens on the tree.[116] The finding of this enzyme in the apple was used in a postulation as to the cause of "water core." It was thought that high summer temperatures (110°F.) were optimum for plant diastases and hence there was premature hydrolysis of starch grains in the apple tissue. This in turn was responsible for an abnormal osmotic relation in the fruit which produced flooding of intercellular spaces with water.[116]

2. OXIDASES

When an apple is cut the exposed tissues rather quickly turn brown in most varieties. Apple juice when first pressed out is rather light colored but it quickly turns brownish in the presence of air. This browning is presumed to be due to the oxidation of certain cell constituents like the tannins by an enzyme system called the *oxidases*. It has often been assumed that there was some connection between the oxidases and plant respiration. Just what this connection may be in apple tissue is not clear. For example, the oxidase activity of Winesap apples is higher than that of Yellow Transparent and yet the respiration rate of the latter is much more rapid.[117]

[115] B. S. Meyer and D. B. Anderson, *Plant Physiology* Van Nostrand, New York, 1939.
[116] C. P. Harley and D. F. Fischer, *Proc. Am. Soc. Hort. Sci., 28,* 561 (1931).
[117] B. D. Ezell and F. Gerhardt, *J. Agr. Research, 56,* 365 (1938).

Peroxidase System. Early studies of the chemistry involved in the darkening of apple tissue established the fact that brown color results from the oxidation of a *chromogen* by a *peroxide* in the presence of a *peroxidase*.[117a,117b] Peroxidases are capable of catalyzing the transfer of oxygen, linked as a peroxide, to oxidizable substances. The chromogen is believed to be a *tannin* belonging to the catechol group and *hydrogen peroxide* has been identified as the peroxide involved.[117c] A study of the peroxidase of Gravenstein apples showed that it was highly specific in catalyzing the oxidation, by hydrogen peroxide, of hydroxyhydroquinone, *p*-aminodimethylaniline, *p*-phenylenediamine, *p*-aminophenol, 2-amino-4-nitrophenol, and 5-aminosalicylic acid into colored compounds.[117e] Activity was also found in the catalytic oxidation of catechol, hydroquinone, tannin (oeno), and pyrogallol among other reagents, but no activity was observed with cresols, phenol, or tannic acid.

Guaiacol, pyrogallol, and *o*-phenylenediamine were used as substrates in a study on the peroxidase activity of enzyme extracts prepared from McIntosh apples.[117d] Of these, *o*-phenylenediamine was found most sensitive to colorimetric measurements of peroxidase activity while pyrogallol was least sensitive. Maximum activity was observed at *p*H 5.5 with guaiacol, at *p*H 5.1 with *o*-phenylenediamine, and at *p*H 7 with pyrogallol. Maximum activity was observed with guaiacol as substrate at 86°F. (30°C.), with pyrogallol at 120 to 122°F. (49 to 50°C.), and with *o*-phenylenediamine at 104 to 140°F. (40 to 60°C.). Peroxidase activity was inhibited at high concentrations of hydrogen peroxide, inhibition being greatest with the guaiacol substrate. Peroxidase activity of the extract with guaiacol was found to be increased by the addition of sulfur dioxide within the concentration range of 200 to 420 p.p.m., but was completely inhibited at concentrations of 440 p.p.m. Sulfur dioxide inhibited peroxidase activity with pyrogallol and *o*-phenylenediamine substrates at all concentrations and activity ceased at concentrations of 440 p.p.m. Peroxidase activity was delayed by the presence of ascorbic acid, which

[117a] M. W. Onslow, *Biochem. J., 14,* 541 (1920).
[117b] E. L. Overholser and W. V. Cruess, *Calif. Agr. Expt. Sta. Tech. Paper, 7,* 1923.
[117c] A. K. Balls and W. S. Hale, *Ind. Eng. Chem., 27,* 335 (1935).
[117d] R. R. Reddi, W. B. Esselen, Jr., and C. R. Fellers, *Food Technol., IV,* 63 (1950).
[117e] M. A. Joslyn, *Food Inds., 18,* (8) 1204, 1334 (1946).

appeared to act as a preferential substrate. Increasing concentrations of both dextrose and sucrose resulted in decreasing enzyme activity, but the inhibiting action of dextrose was most pronounced. In this study no inhibiting effect was observed on the addition of sodium chloride, although thiourea, allylthiourea, and glutathione exerted inhibiting effects. Peroxidase activity on the three substrates studied was destroyed by heating at 176°F. (80°C.) for 10 minutes. Enzyme activity remained after heating at lower temperatures for up to 20 minutes and after periods of 5 minutes or less at 176°F. (80°C.) and in these cases activity was regenerated after 20 hours at 77°F. (25°C.). In no case was activity observed to return after complete heat inactivation.

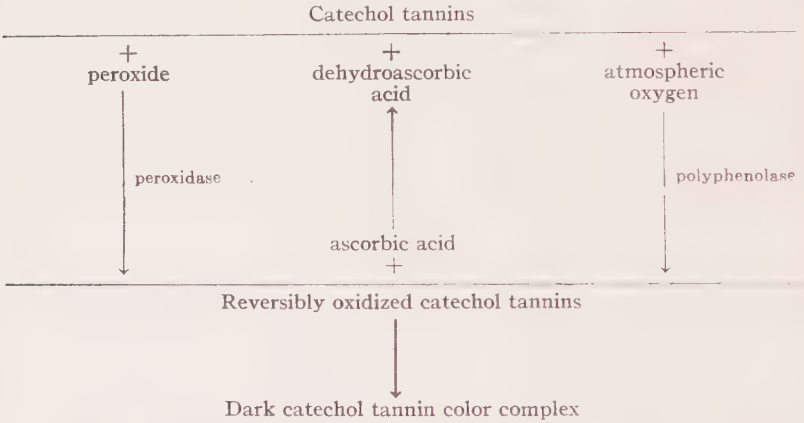
Polyphenolase System. Studies of the enzyme system in apples indicate that *polyphenolase* (polyphenol oxidase) may play a more important part in the darkening of apples than does peroxidase.[117f] Polyphenolase is capable of catalyzing the oxidation of polyphenols by atmospheric oxygen. Apple juice was found to contain not more than 30% as much peroxidase as polyphenolase, based on the same method of measurement. The peroxidase was ineffective after the first few minutes from the time of extracting the juice because the small amount of hydrogen peroxide present in the fresh fruit was quickly oxidized. Even in the presence of excess hydrogen peroxide the peroxidase activity was found to decline to a negligible value in a few minutes. The natural polyphenols present in apples were, however, found to be oxidized about ten times as fast by peroxidase as by polyphenolase. From these studies it was concluded that polyphenolase is the main oxidizing enzyme in apples, although darkening when apple tissue is first crushed may be due to peroxidase to the extent of 40% or perhaps more because of the hydrogen peroxide present in the fresh tissue. After a few minutes the hydrogen peroxide is completely utilized and the oxidation is then due primarily to polyphenolase.

Ascorbic Acid Destruction. Darkening of apple tissue and oxidation of ascorbic acid were found to be intimately related, and the first does not proceed until all of the ascorbic acid present is converted to the dehydro form.[117f,117g] The peroxidase and polyphenolase are

[117f] J. D. Ponting, The Enzymic Oxidation of Ascorbic Acid. *Thesis*, Univ. Calif. Grad. Div. Northern Section, 1944.
[117g] S. W. Johnson and S. S. Zilva, *Biochem. J., 31*, 438 (1937).

not capable of catalyzing ascorbic acid oxidation directly but rapidly accomplish its oxidation in the presence of certain phenolic compounds that may be reversibly oxidized by them. The reversible oxidation of the phenolic compounds is not accompanied by development of color, and the complex color substances do not form, according to these studies, until all of the ascorbic acid present has been oxidized.

The chemical changes catalyzed by these enzymes in the darkening of apple tissue and juice and in the destruction of ascorbic acid may be represented by the following reactions:



Apple varieties like Cortland which do not readily turn brown when exposed to air are presumably either low or lacking in either the oxidases or in tannin compounds (or both).[118] It has been found when making oxidase measurements on apple tissue that higher values were obtained when ascorbic acid was used as a substrate than when glucose was used.[119]

Oxidase Activity. The region of greatest activity in apples seems to differ with varieties. In Winesap apples the greatest activity was found in the core region but in Maiden Blush it was greatest in the periphery.[120]

The age of the fruit seems to have some influence on oxidase activity. Before harvest the oxidase activity of apples was found to de-

[118] E. L. Overholser and W. V. Cruess, *Univ. Calif. Col. of Agr. Tech. Paper*, 7, 1923.
[119] B. D. Ezell and F. Gerhardt, *J. Agr. Research*, *60*, 89 (1940).
[120] B. D. Drain, *Botan. Gaz.*, *82*, 183 (1926).

crease with increasing maturity on the tree.[121,122] In some cases it has been found that oxidase activity increased if the fruits were left on the tree beyond the normal time of picking but in other cases it did not.[122]

Oxidase activity differs between *varieties*, but as has already been stated, it is difficult to correlate oxidase activity with length of keeping of a given variety. There has been found to be higher oxidase rates in Delicious and Golden Delicious at harvest time than in Jonathan and Yellow Newtown.[122]

The *location* in which the trees are growing may have some bearing on oxidase activity. Jonathans grown at an elevation of 2400 feet in Washington had a higher oxidase activity than those grown at 850 feet. There was little difference in Winesaps grown at the two altitudes, however.[122]

There are *seasonal variations* within the same variety grown in the location with regard to oxidase activity.[122]

The presence of alcohol in apple tissue seems to stimulate the activity of oxidase.[117] Concentrations were probably low enough so that they were not toxic to the enzyme.

3. CATALASE

This enzyme activates the reduction of hydrogen peroxide to water and oxygen. The metabolic significance of this enzyme in apple tissue is not known although its presence has been often demonstrated. It has been suggested that the function of catalase might be the removal of toxic peroxide formed in the course of metabolism. It is true that tissues that are metabolically very active are usually characterized by a high level of catalase activity. On the other hand, it is difficult to see any correlation between catalase activity and respiratory differences between varieties of apples, for example. Oldenburg apples respire faster than Winesap apples and yet they have a lower catalase activity.[120] Little if any relation between catalase activity and respiration rate has been found in Washington-grown Jonathan and Winesap apples.[122] In other words, we do not really know the true function of catalase in apple tissue.

In normal apples the activity of this enzyme has been found to be highest in the skin and least in the region immediately under the

[121] J. C. Hinton, *Ann. Rept. Univ. Bristol Hort. Research Sta. 1934, 29–52* (1935).
[122] B. D. Ezell and F. Gerhardt, *J. Agr. Research, 65,* 453 (1942).

skin. The intensity, however was found to increase again as samples were taken toward the core region away from this low catalase area under the skin.[123]

The age of the fruit has some influence on the amount of catalase activity within a given variety. It has been found to increase steadily from July to harvest time in Jonathan and Winesap.[122]

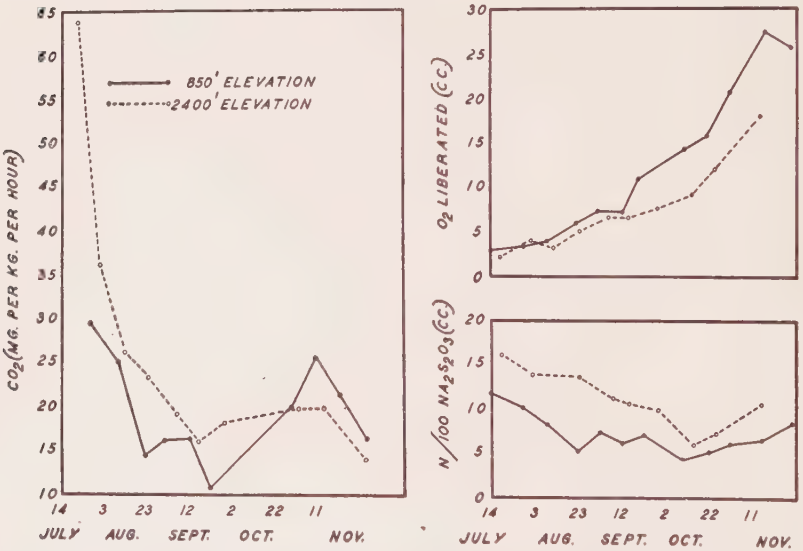


Fig. 16. The respiration rate (left), catalase activity (upper right), and oxidase activity (lower right) of Jonathan apples during the growing season from orchards at two elevations. Measurements made at 67°F. (20°C.).[122]

Catalase activity varies from *variety* to *variety*. It is greater in Winesaps than in Oldenburg and greater in Jonathans than in Winesaps.[120,122]

There are marked variations in catalase activity within a given variety from season to season.[122] Differences in altitude seemed to have no effect on the catalase activity of Winesaps but it has been noted that the activity in Jonathans was less at an altitude of 2400 feet than at 850 feet.[122]

Nitrogen fertilization has been found to increase the catalase

[123] P. Harding. *J. Agr. Research, 53,* 43 (1936).

activity of Wealthy and Staymen Winesap apples during their development on the tree.[124]

4. OTHER ENZYMES

Tests for *pectin* hydrolyzing enzymes in apple tissue have given negative results.[125]

Tests for *invertase* which converts sucrose into glucose and fructose, have given negative results in apple tissues. The same is true for *tannase* (converts tannin into its hydrolytic products) and *emulsin* (splits glucosides).[126]

An *esterase* which will break down ethyl malonate and which is similar in its reactions to steapsin has been found in apple flesh.[126]

Small amounts of *proteases* (protein splitting enzymes) have been found in apple tissue. These were of the trypsin or papain type but not of the erepsin type.[126] Amylase and peroxidase have been found in apple tissue.[126a]

J. Vitamins

Most of the investigational work that has been done on vitamins in apples has been done after harvest in the fall. The work that has been done during the development of the fruit on the tree is briefly reviewed in the following paragraphs. The vitamins other than ascorbic acid have not yet been studied during fruit development on the tree.

Vitamin C is known chemically as ascorbic or cevitamic acid. The absence of this vitamin from the human diet gives rise to scurvy. The pure substance has the formula $C_6H_8O_6$ and is readily soluble in water. It is rather easily destroyed by heat and is readily oxidized in the presence of air. The compound first formed upon the oxidation of ascorbic acid may be easily reduced again to ascorbic acid. The reduced form is known as L-ascorbic acid and in the reversibly oxidized form as dehydroascorbic acid. Ascorbic acid is present in the apple as both L-ascorbic acid and as dehydroascorbic acid. The total quantity of ascorbic acid present in these two forms remains constant per unit of fresh weight during growth of the fruit on the tree. The proportion,

[124] J. H. Gourley and E. F. Hopkins, *Ohio Agr. Expt. Sta. Bull.*, 479, 1931.
[125] Z. I. Kertesz, *Plant. Physiol., 18,* 308 (1943).
[126] R. W. Thatcher, *J. Agr. Research, 5,* 103 (1931).
[126a] A. C. Hulme, *Nature, 158,* 588 (1946).

however, of L-ascorbic acid increases and that of dehydroascorbic decreases with advancing maturity on the tree.[127-129]

An oxidase system is present in apple tissue which will readily oxidize ascorbic acid. It is thought that though copper may be present in traces in apple tissue the breakdown of ascorbic acid is not catalyzed by copper but by some enzyme.[119]

Spraying of the trees in various ways during the growing season has not been found to have any effect on the ascorbic acid content of the fruit.[130]

K. Respiration

What is Respiration? Respiration is a characteristic of all living cells. In cellular respiration there is oxidation of organic compounds (such as sugars, organic acids, and fats) with the simultaneous reduction of molecular oxygen to water, carbon dioxide, and other respiratory products. This oxidation process may be complete with all the carbon converted to carbon dioxide or it may be incomplete with the formation of organic acids and other products. As contrasted to aerobic respiration (in the presence of free oxygen) "fermentation" may occur in the absence of oxygen. In this type of respiration there is degradation or breakdown of an organic molecule like glucose mainly into two or more simpler molecules. This type of mechanism (sometimes called anaerobic respiration) does not require molecular oxygen and may or may not be suppressed by molecular oxygen.[131]

Because the cells of the apple fruit carry on respiration the apple is said to be a living organism—whether it is on the tree or harvested. Finally the fruit dies. The fruit may become unmarketable some time before it actually dies because it is usually mealy and inedible by the time it is presumably dead. Of course, parasitic or nonparasitic disorders of the fruit may hasten the death of the fruit. A very natural question that arises here is just when is an apple "dead." Certainly no one can arbitrarily say an apple is dead or alive without making very careful cellular respiration measurements.

The equation for aerobic respiration is written as follows:

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + \text{energy}$$

[127] S. S. Zilva, F. Kidd, and C. West, *Rept. Food Inv. Board, 1937,* 114 (1938).
[128] S. S. Zilva, F. Kidd, and C. West, *ibid., 1935,* 110 (1936).
[129] S. S. Zilva, F. Kidd, and C. West, *ibid., 1936,* 136 (1937).
[130] Anon., *Hoosier Hort., 27,* 133 (1945).

In the light of what was said earlier on the nature of respiration it is obvious that this is an oversimplification. It is usually assumed that a hexose sugar like glucose (dextrose) is involved in fruit respiration. It is possible that some other sugar may be involved like fructose or at times organic acids or even fats might be involved directly or indirectly. Certainly respiration is not a one-step process as outlined in the equation. There are probably many side reactions or intermediate steps involved. In the light of our present knowledge of fruit respiration, it would seem just as well in this book to avoid all the theoretical possibilities of side reactions and admit that the equation is an oversimplification and yet hew to the traditional line of using this equation in the discussion of respiration.

One of the important things to note in the respiration equation is that energy is evolved in the process. Because the assumption is most commonly made that a hexose sugar is involved in respiration it is stated that 673 kilogram-calories of heat per mole of hexose are evolved.[131] Actual calorimetric studies of heat evolved by apple fruits have shown that practically all of the energy evolved is in the form of heat.[132]

The chemical equation noted above for respiration tells us the fundamental fact that for the oxidation of one mole of a hexose sugar, six moles of oxygen are required and that six moles each of carbon dioxide and water result from the oxidation. Since equimolar weights of gases occupy the same volume (Avogadro's hypothesis) the volume of oxygen consumed when a hexose is oxidized is equal to the volume of carbon dioxide released.[133] It is well to remember this principle when considering what happens in controlled atmosphere storage of apples.

The respiration of apples is commonly measured by determining the amount of carbon dioxide evolved. The rate of respiration is expressed as milligrams of carbon dioxide produced per kilogram of fruit per unit time. Sometimes the number of milligrams of oxygen consumed per kilogram of fruit per unit time is used as an expression of respiration rate. It is often convenient to express the cumulative respiration rate of fruit. This is done by measuring the respiration

[131] D. R. Goddard, *Science, 101,* 352 (1945)

[132] W. P. Green, W. V. Hukill, and D. H. Rose, *U. S. D. A. Tech. Bull. 771,* 1941.

[133] B. S. Meyer and D. B. Anderson, *Plant Physiology.* Van Nostrand, New York, 1939.

rate day by day or hour by hour and calculating the *total* amount of carbon dioxide (or oxygen consumed) produced over a period of time. For example, if the rate of respiration of a given lot of apples is 15 milligrams per kilogram per hour for three successive days the cumulative rate would be 15 times 24 (hours in the day) times 3 (number of days) or 1.080 grams of carbon dioxide.

Sometimes it is convenient to express the *respiratory quotient.* This is obtained by dividing milligrams CO_2 evolved by milligrams O_2 consumed. Under ordinary aerobic conditions if simple sugars

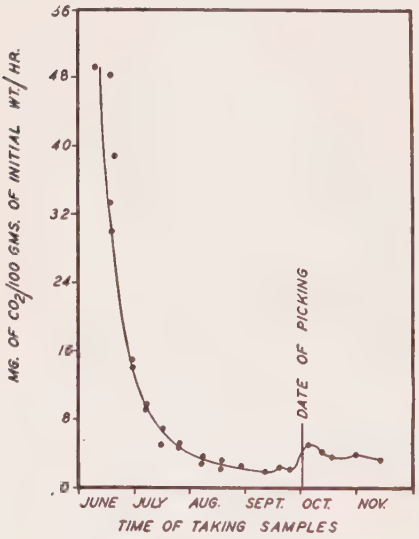


Fig. 17. Changes in the respiration rate of McIntosh apples during the growing season and after the normal harvesting time. Measurements made at 71.6°F. (22°C.).[136]

are utilized in the process and if all the oxygen is consumed in their combustion, the volume of oxygen utilized would be equal to the volume of carbon dioxide produced and the respiratory quotient would be 1.0. If organic acids are the substrate of respiration the quotient is greater than 1.0. Thus the respiratory quotient for the complete oxidation of tartaric acid would be 1.6. If fats are the substrate of respiration the respiratory quotient would be less than 1.0. Here again is an oversimplification because we do not know that carbohydrates are the sole substrate at any one time. There may be a mixed substrate. The respiratory quotient for apples varies with the age of the fruit (see below).

Respiration Rate of Apples during Development on Tree. Comparatively little experimental work has been done on respiration measurements of apples while still attached to the tree. In most of the investigations on this topic the procedure has been to remove the fruits from the tree and measure respiration rate within 24 hours. This technique, however, seems to have considerable justification because it has been found that fruits attached to the tree seemed to have respiration rates similar to those removed from the tree only a short time previously.[134]

Studies made on both Jonathan[135] and McIntosh[136] apples as they matured on the tree (measurements made right after harvest) have shown approximately the same general trends in respiration rate. Respiration was very rapid during the period just following fruit setting. This high rate declined rapidly in early summer and in late summer decreased less rapidly. In McIntosh the rate was over six times as rapid in mid-June as it was in mid-September.[136]

The respiratory quotient in Jonathan apples was found to decrease from 0.84 on May 23 to 0.46 on June 28th. After this time it began to increase and by July 26th it was 0.92.[135]

Respiratory quotient values would undoubtedly vary with variety and possibly with location during the growing period. For example, with Granny Smith apples in Australia the respiratory quotient varied little from a value of 1.0 during development on the tree.[137] It was also shown in this Australian study that when respiration rate was based on a per fruit basis instead of a weight basis that there was no decline in apparent respiration even though there was a marked decline on a weight basis.

It is interesting to note that the rapid decline noted in respiration rate during the first month of development on the tree seems to correspond with the period of rapid cell multiplication in the young fruits.

[134] F. Kidd and C. West, *Rept. Food Inv. Board, 1937,* 114 (1938).
[135] S. Shaw, *Plant Physiol., 17,* 80 (1942).
[136] G. Krotkov, *ibid., 16,* 799 (1941).
[137] F. M. V. Hackney, *Proc. Linnean Soc. N. S. Wales, 49,* 91 (1944).

CHAPTER VI

CHEMICAL CHANGES AND PHYSIOLOGY OF APPLE FRUIT AFTER HARVEST

Knowledge of the chemical changes and physiology of apple fruits after harvest is very useful in understanding what happens to the fruits in storage, in the marketing channels, and in the hands of the consumer. Such knowledge may even be useful in predicting what may happen under a given set of conditions. For example, what is likely to happen to a lot of apples if they are packed in a gas-tight package for an extended period of time? It will be seen that certain favorable results may be attained by such a practice yet these may very likely be offset by some very serious undesirable results. The fruit handler is very anxious to preserve fruit for long periods of time on some occasions. How can he best do it without impairing the quality of the fruit?

A. Transpiration (Water Loss)

Transpiration has already been defined as the loss of water in the vapor form from living tissues. After apples are harvested they continue to transpire. After harvest they have no means of obtaining water so that transpiration losses cannot be compensated for by gains in water from any source. Unlike some leafy vegetables, apples cannot absorb water vapor from the air when they become wilted or shrivelled. Hence transpiration after harvest can only be recorded as a "net loss" to the fruit.

At harvest time apples have on the average about 84% of water. Unless transpiration is checked by some means the water content may be reduced considerably. By the time most varieties of apples have lost 5 to 7% of their weight they are so severely shrivelled and wilted that they cannot be marketed without taking a severe financial loss. In a general way one might say that the less water lost during the handling and storage period the better; certainly not more than

2 or 3% of weight should be lost during the period from picking until final consumption.

Excessive transpiration should be avoided for a number of reasons. One reason is that there is a weight loss. Since apples are not usually marketed in large quantities on a weight basis but on a volume basis, this is not as serious as it might be with some food products. A second reason is that apples that have transpired considerably are shrivelled. This wilting leaves the skin of the fruit in a wrinkled appearance which is very unsightly to the consumer. While the wrinkling may not be readily apparent to the eye it often is when the consumer picks up the fruit and squeezes the skin gently between two fingers. A third reason is that apples which have lost considerable moisture through transpiration have reduced eating quality. The apples are not as crisp and turgid as they should be for best eating quality.

FACTORS AFFECTING RATE OF TRANSPIRATION

Effect of Water Vapor Pressure Deficit. All liquids have a certain vapor pressure. Consider an open pan of water sitting on a table at room temperature. The water will gradually evaporate if the moisture content of the air is not too high. If the air is not saturated with moisture, the air will have a low vapor pressure and water will evaporate rapidly. This is true because gases always move from a point of high to a point of low concentration. As long as there is a difference between the water vapor concentration of the air and that of the air at the surface of the water, there will continue to be evaporation. The difference in the vapor pressure of the water surface and that of the surrounding air is called the *vapor pressure deficit.* Another factor which will very markedly affect the vapor movement from the pan of water is the temperature of the water. If a flame is applied to the bottom of the pan, water evaporates more rapidly because the vapor pressure of the liquid is increased. If a lid is placed on the pan, it is a commonly observed fact that pressure will build up under the lid. This is another explanatory observation that should indicate that water vapor can be expressed in terms of pressure. This pressure is commonly measured in millimeters of mercury.

Another conception that must be clear before studying transpiration in detail is that of "relative humidity." This term may be defined as the percentage of saturation of the atmosphere with water vapor at any one temperature. Warm air can "hold" more water in the

vapor form than cold air can. A film of moisture—or dew—forms when the temperature is lowered to the point where the air can hold no more water. It will be indicated below that it is possible to have a relative humidity of 100% in both the atmosphere of a storage room and in the intercellular spaces of the apple and yet have a vapor pressure gradient.

The fundamental reason why fruits transpire is that there is a difference between the water vapor pressure of the fruit's internal atmosphere and that of the surrounding atmosphere. The relative humidity of the internal atmosphere of apples is *presumed* to be 100%

TABLE 14. Relation between Relative Humidity, Vapor Pressure, and Vapor Pressure Deficit[142]

Temperature		Actual vapor pressure (mm. Hg) at indicated relative humidity (*read down*)			
°F.	°C.	50%	70%	90%	100%
32	0	2.29	3.21	4.12	4.58
41	5	3.27	4.58	5.89	6.54
50	10	4.60	6.45	8.29	9.21
68	20	8.77	12.28	15.79	17.54
77	25	11.88	16.63	21.38	23.76
		50%	30%	10%	0%
		Vapor pressure deficit (mm. Hg) at indicated relative humidity (*read up*)			

under normal circumstances. Of course, after the fruits become somewhat desiccated, it is doubtless not that high. Hence, if apples are held in an atmosphere with a relative humidity of less than 100%, water vapor will move out of the fruit into the atmosphere.[138,139] This is the reason then why apples "ideally" should be held in an atmosphere of 100% relative humidity from the standpoint of preventing transpiration losses.

Relative humidity *per se* is not the only atmospheric factor that will influence the rate of transpiration of apples. Transpiration may be more rapid in a given lot of apples at 85% relative humidity at 36°F. than it is in a similar humidity at 32°F. (0°C.).[140] This is

[138] A. J. M. Smith, *Rept. Food Inv. Board, 1933,* 105 (1934). *Ibid., 1929,* 54 (1930).
[139] W. H. Smith, *Ann. Appl. Bot., 20,* 220 (1933).
[140] M. H. Haller and J. M. Lutz, *U. S. D. A. Tech. Bull.,* 776, 1941.

due to the *temperature* factor as it affects vapor pressures. As the temperature is raised from 32°F. (0°C.) to 36°F. (2°C.) the vapor pressure of water rises and the difference or deficit between fruit and atmospheric vapor pressures is increased. Hence, transpiration is greater at the same humidity at a high temperature than it is at a low temperature. An examination of Table 14 will reveal that the vapor pressure deficit between apples (with presumably 100% relative humidity) at 32°F. (0°C.) in air at 50% relative humidity is 2.29 mm. of mercury. This deficit is only about one fifth that in air with 50% relative humidity with both fruit and air at 77°F. (25°C.).

Another illustration of the interrelation of temperature and vapor pressures is found with storage of warm fruit in a cold room. Let us assume that a lot of apples with a field temperature of 77°F. (25°C.) is moved into a room at 32°F. (0°C.) with 100% relative humidity. From the standpoint of relative humidity alone, one would assume that there would be no transpiration because both apples and air had a saturated atmosphere. However, an examination of Table 14 will reveal that there is a water vapor pressure deficit of 19.18 mm. of mercury. This deficit (with identical relative humidities) is much greater than the deficit that would occur between apples (with 100% relative humidity) in air at 50% relative humidity at 41°F. (5°C.). Of course, in this particular illustration apple temperature would in time reach air temperature and the vapor pressure gradient would disappear. However, transpiration is very rapid until that gradient in temperature is eliminated. It emphasizes the necessity of rapid cooling of fruit.

Most of the foregoing discussion on vapor pressure deficits has been based on more or less hypothetical considerations. The question arises as to the magnitude of the practical effects that might occur with apples. When warm apples are moved into a cold storage room, transpiration is very rapid—but not rapid enough to result in actual wilting. With a very leafy product like lettuce actual wilting has been observed when the warm product was placed even in a saturated atmosphere at 32°F. The question arises then why this effect is of importance with apples if actual wilting does not take place during the cooling period. Suppose that only 1% of the fresh weight of apples is lost as a result of placing warm fruit in a cold storage room in which cooling is not rapid. This loss of itself is not very significant but added to the other losses in weight that are likely

to ensue before the apples reach the consumer, it becomes quite important.

The question arises as to how transpiration losses can be kept to a minimum during the cooling operation. It is inevitable that there is going to be a temperature difference between the cold storage room air and that of the fruit during the initial stages of the cooling period. This inevitable vapor pressure deficit resulting from such a temperature difference can be kept to a minimum by prompt, rapid cooling.

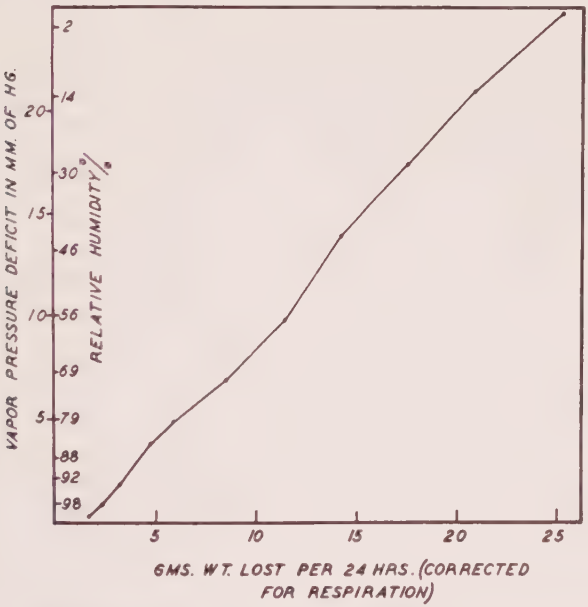


Fig. 18. Transpiration rate of 45 McIntosh apples during a 24-hour period as affected by relative humidity and vapor pressure deficit at 77°F. (25°C.).[142]

Very rapid cooling by means of immersion in ice water (*hydro cooling*) has been shown to result in no transpiration losses with apples as a result of such temperature differences.[141] Such hydrocooling with apples may not be practical, however, in large scale operation.

It has been shown by actual experimentation that the transpiration rate of apples is directly proportional to the water vapor

[141] H. J. O'Reilly, *Unpublished data*, Cornell Univ., 1946.

pressure deficit.[142] Figure 18 illustrates this point. After considerable transpiration has taken place and there is shrivelling of the skin, this relationship may not be a straight-line one; that is, there is enough

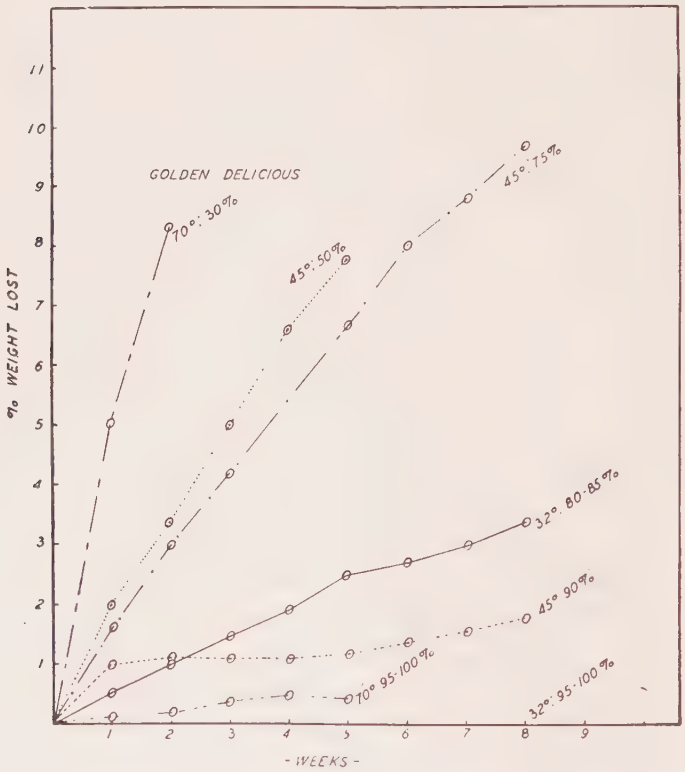


Fig. 19. Weight losses in Golden Delicious apples at different temperatures (°F.) and relative humidities.

resistance to the passage of water through shrivelled apple fruit skins that transpiration is no longer directly proportional to the water vapor pressure deficit. Hence, the time factor may upset this straight-line relationship. Until this does become a factor one can use Table 14 as a method of estimating relative transpiration rates under different humidity and temperature conditions for a given variety (Fig. 19).

[142] S. A. Pieniazek, *A Study of Factors Influencing the Rate of Transpiration of Apple Fruits*. Thesis, Cornell Univ., 1942.

There is another temperature effect on transpiration that may affect the locus of transpiration. It has been shown that if one side of an apple is colder than the other in storage, there will be a distillation of water from the warm side to the cold side, leaving the warm side

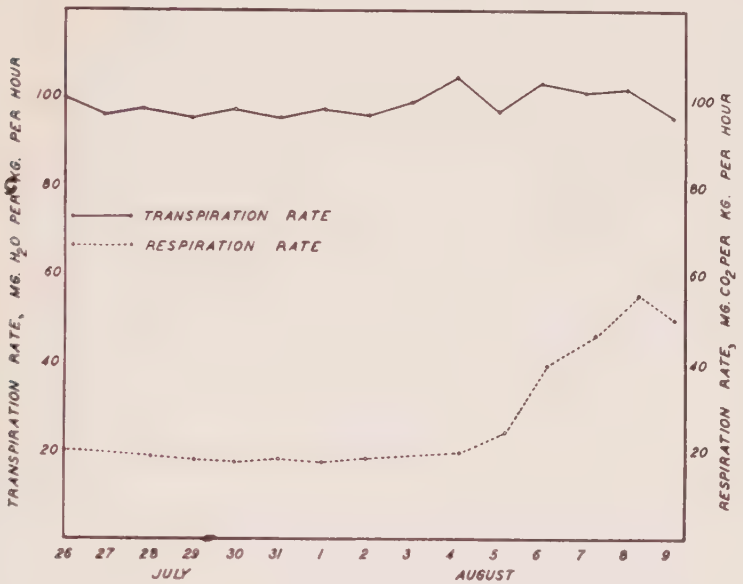


Fig. 20. Relation of transpiration rate and respiration rate of Duchess of Oldenburg apples at 80°F. (27°C.).[142]

shrivelled.[143] This may occur when one side of an apple fruit is cooled more rapidly than another. This phenomenon may be explained by the fact that on the warm side of the fruit the vapor pressure is greater than on the cold side and the vapor passes to the low pressure side of the fruit. The vapor undoubtedly passes through the intercellular spaces which are more or less interlacing from one side of the fruit to the other.

Effect of Time of Harvest on Transpiration. It has been a common observation that apples picked in a rather immature condition shrivel faster in storage than fruits picked at the proper time. For example, if Golden Delicious apples are examined in storage in the

[143] O. F. Curtis, *Am. J. Botany, 24,* 704 (1937).

spring, those apples that were harvested on September 1st usually show more shrivelling than those harvested in mid-October. Because of this observation it has been assumed by most workers that fruit picked early transpire faster than do mature ones in storage.

Actual experimental work on this subject does not support this observation. It has been found with a number of varieties that the rate of transpiration of apples does tend to be very high early in the growing season (see Chapter V). However, as the season progresses the rate of transpiration declines until or slightly before the usual time for normal harvesting; that is, the transpiration rate of several varieties was found to reach a minimum shortly before the optimum time for picking. After this point was reached, the apples transpired at a faster rate, especially those harvested in an overmature condition[144] (see Fig. 8). Hence, it seems apparent that fruits picked late may actually transpire faster than fruits picked earlier especially if they were picked somewhat past the optimum maturity date for long keeping in storage.

The fact that Golden Delicious apples examined in the spring show more shrivelling if harvested early may be explained in the following ways. (*1*) The apples harvested on September 1st were in storage about six weeks longer than those harvested in mid-October. Hence, it is no wonder that the total water loss was greater in the early-picked fruits. The late-picked fruits had a source of water (being attached to the tree) six weeks longer than did the early-picked ones. (*2*) During the early storage period in most cold storages the relative humidity is likely to be very low. This low humidity may be due to the low refrigerant temperatures used at that time to accomplish rapid cooling of very warm fruit. It might also be due to the drying effect of the wooden containers until the vapor pressure of the wood comes to equilibrium with that of the air. (*3*) The temperature of the storage and that of the fruit is not as likely to be as low as it is in mid-October when the late-picked fruits were placed in storage.

It will be noted later in the text that the respiration rate of apples varies with the age of fruit, but no correlation has been found between respiration and transpiration rates (see Fig. 20).[142] As fruits grow old the rate of transpiration gradually diminishes after the postharvest peak has been reached. This decline in rate in older

[144] S. A. Pieniazek, *Proc. Am. Soc. Hort. Sci., 42,* 231 (1943).

fruits is probably due to changes in the physical structure of the skin and possibly to certain internal factors.[145]

Effect of Fruit Size. Since transpiration is essentially a surface phenomenon, it is not surprising that a bushel of small apples transpires at a faster rate than a bushel of large apples. In other words, a bushel of small apples loses more weight in storage than a bushel of large apples. In fact, it has been found that the transpiration rate of several varieties of apples in storage was directly proportional to the surface area of the fruit.[142] Because of this strong relationship between fruit surface area and transpiration rate, it is probably best that transpiration losses should always be expressed on a surface area basis rather than on a fruit weight basis as they usually are.

Effect of Physical Nature of Fruit Skin. It is obvious that transpiration from apples is unlike evaporation from a free water surface. The skin of the fruit acts as a natural deterrent to the passage of water vapor out of the fruit. Just how much the skin of the fruits of different varieties and the skin of fruit of the same variety affect transpiration rate is not entirely clear.

It is commonly stated that the thickness of the skin and of the cuticle in particular markedly affects the rate of transpiration.[145,146] Such statements are usually based on the observation that a variety of apples like Golden Delicious shrivels badly in storage and that it has a "thin cuticle." That the skin inhibits transpiration is inescapable. It has been shown that a unit area of free water surface will evaporate 70 times more water than a unit area of uninjured fruit of an apple per unit of time.[147] It is also true that when the waxy layer on the surface of the fruit is removed by brushing or by washing with severe treatments (such as sodium silicate) the rate of shrivelling is greatly increased.[148]

While it is quite true that the nature of the skin or the cuticle in particular may have some bearing on transpiration rate, careful studies on cuticle thickness as related to this rate have not always shown a good correlation.[142] While it has been found that Golden Delicious does shrivel badly and may have a relatively thin cuticle

[145] M. B. Cummings and P. M. Lombard, *Vermont Agr. Expt. Sta. Bull.*, 186 1915, pp. 99–136.
[146] W. Perry and J. M. Martin, *Trans. Iowa State Hort. Soc., 52,* 18 (1917).
[147] W. H. Smith, *Rept. Food Inv. Board, 1930,* 55 (1931).
[148] R. E. Marshall, F. L. Overley, and K. Groves, *Wash. Agr. Expt. Sta. Bull., 330,* 1936, pp. 1–28.

as compared to some varieties, very little correlation has been found between cuticle thickness of different varieties and transpiration rate. A more likely reason as to why Golden Delicious apples shrivel badly is the fact that there are numerous breaks and cracks in the cuticle.[149] The cuticle on this variety is not continuous as it is on most varieties, and the cracks leave the epidermis exposed and uncovered (see Fig. 2 on page 28).

Other skin factors that may affect transpiration rate are the number and size of lenticels. It has been shown, however, that about 70% of apple transpiration is cuticular and only about 30% lenticular.[142] Cell wall thickness and arrangement of cells in the skin may also be factors in determining transpiration differences between various varieties.[145] Additions of wax to the skin of certain varieties of apples may pay commercially under some circumstances.[150] Use of special wraps such as cellophane, pliofilm, aluminum foil, or latex may be of some practical value in this connection (see Fig. 45). The precaution that must be kept in mind in connection with putting "moisture-proof" wraps or coatings on fruits is that they must be reasonably permeable to the passage of oxygen and carbon dioxide; otherwise off flavors and physiological disorders are likely to occur.

Effect of Air Movement. It would seem logical to suppose that transpiration would be accelerated by air currents passing over fruit in storage if a vapor pressure gradient exists. The magnitude of this effect is of commercial interest because some storages operate with forced air circulation, others only with slow natural convection currents.

Several studies have shown accelerated transpiration rates of 30% to 100% when air currents of varying velocities were used with apples.[151] Some of these experiments are open to criticism in that the exact relative humidity around the fruits was not measured during the trials. When fruits are subjected to different air flow rates in closed containers it is difficult to maintain the humidity at a constant level. For example, when a slow air flow rate is used, the relative humidity around the fruit is usually a little higher than the theoretical value, even though the air has been conditioned by passing it through sulfuric acid–water mixtures. Hence it is difficult to attribute differences in

[149] A. Meyer, *Proc. Am. Soc. Hort. Sci.*, 45, 105 (1944).
[150] H. A. Baghdadi and R. M. Smock, *ibid.*, *42*, 238 (1943).
[151] W. H. Smith, *Rept. Food Inv. Board, 1931*, 152 (1932).

transpiration to velocity rates alone in studies where humidity values are not specified. This objection has been overcome by moving apples through still air at a known velocity by means of a turntable.[152]

It has been noted that the effect of air movement on transpiration of apples was negligible, not exceeding an increase of 5%. The effect was very small when high relative humidities were used, and, of course, high humidities are recommended in cold storage practice.[142] The technique of moving the apples through air at a known humidity was used in this study.

It is sometimes claimed by storage operators that apples stored in forced air rooms show more shrivelling than apples in "still air" rooms. It has not been shown, however, that the relative humidity was identical in each case around the fruits. In the light of recent work it would seem safe to conclude for apples at least, that rather high velocities of air do not markedly affect transpiration if the humidity is as high as it should be.[142] The advantage of rapid cooling with moving air would doubtless outweigh the disadvantages of slightly increased transpiration.

B. Carbohydrates

1. SUGARS

The importance of the amounts and types of sugars in apples after harvest cannot be overemphasized. Fruit eating quality is determined in large part by "relative astringency" which in turn is governed by the relative amounts of acids, sugars, and astringents. The amounts of sugars in apples are not great enough to mark this fruit as a good food source from the standpoint of calories, or fuel for the human body. A well-fed man needs about 3000 calories per day in his diet and one large "apple" supplies about 100 calories.[152a] Just what relation sugar content in the fruit may have to length of storage life and other storage factors is not yet known. Some investigators have claimed that long storage life of apples could be associated with a high sucrose content and a low nitrogen level in the fruit.[153] This finding has not been widely accepted as a determining factor in fruit storage life, however.

[152] A. J. M. Smith, *ibid., 1932,* 117 (1933).

[152a] C. L. Hunt, *Nutritive Value of Fruits, Vegetables and Nuts.* U. S. D. A. Yearbook Sept., 927, 1925.

[153] H. K. Archbold, *Ann. Botany, 42,* 541 (1928).

Sugars are also important in that one of them at least (glucose) acts as a substrate for respiration. The types of sugars found in apples and their relative proportions have been discussed in Chapter V.

Total sugars normally increase for at least a short period after harvest. This increase in percentage of total sugars is due to the hydrolysis or breakdown of starch[154] and to conversion from other

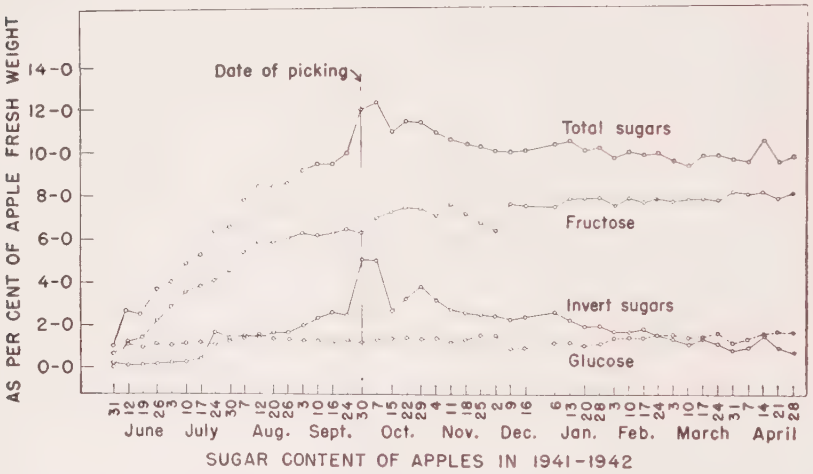

AS PER CENT OF APPLE FRESH WEIGHT
14-0
12-0
10-0
8-0
6-0
4-0
2-0
0-0
Date of picking
Total sugars
Fructose
Invert sugars
Glucose
31 12 19 26 3 10 17 24 30 7 12 20 26 3 10 16 24 30 7 15 22 29 4 11 18 25 29 6 16 6 13 20 28 3 10 17 24 3 10 17 24 31 7 14 21 28
June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April
SUGAR CONTENT OF APPLES IN 1941-1942

Fig. 20A. Sugar content of McIntosh apples before harvest and during storage at 35.6°F. (2°C.).[154a]

nonsugar materials.[154a] This increase is then followed by a gradual decline during the remainder of the life of the fruit. The decrease is due to the fact that after all the starch remaining in the fruit has been hydrolyzed there is a net loss of sugar due to respiration (Fig. 20A).

Following harvest there seemed to be some interconversion of one type of sugar to another. For example, there may be conversion of glucose to fructose and vice versa.[155,156] During the late stages of the life of the fruit there may be some replenishment of the sugars being consumed in respiration. This replenishment at least seems possible because there is a breakdown of pectin during the latter part of the life of the apple. Pectin is broken down to galacturonic acid

[154] H. K. Archbold, *ibid., 46,* 407 (1932).
[154a] G. Krotkov and V. Helson, *Can. J. Research, 24,* 126 (1946).
[155] F. Kidd, M. Onslow, and C. West, *Rept. Food. Inv. Board, 1929,* 44 (1930).
[156] F. Kidd, M. Onslow, and C. West, *ibid., 1931,* 52 (1932).

which may be reduced to hexose or oxidized to pentose. In spite of this hydrolysis of pectin materials the total sugars show a net decline during the later part of the life of the fruit.

TABLE 15. LENGTH OF TIME IN STORAGE, PRESSURE TEST AT END OF STORAGE PERIOD, AND CHEMICAL COMPOSITION OF APPLES HELD AT VARIOUS STORAGE TEMPERATURES[160]

Variety	Storage temperature °F.	Storage temperature °C.	Time in storage, days	Pressure test, lbs.	Percentage of sugar: Total	Percentage of sugar: Reducing	Titratable acidity as malic acid, %
McIntosh	[a]		0	13.45	10.17	7.62	0.73
Rosslyn, Va.	70	21	11	8.10	10.77	7.88	0.58
1924–25	60	16	15	8.05	11.20	7.90	0.63
	50	10	21	8.40	10.91	7.69	0.68
	40	4	39	9.10	11.34	8.14	0.68
	36	2	62	9.10	10.84	8.30	0.62
	32	0	87	9.00	11.34	9.24	0.50
	30	−1	108	9.50	11.26	9.22	0.40
Jonathan	[b]		—	11.0	—	—	0.69
Yakima, Wash.	85	30	4	8.00	12.88	9.64	0.47
1923–24	70	21	6	8.10	12.59	8.96	0.54
	60	16	8	7.90	12.38	8.59	0.52
	50	10	11	8.25	12.38	8.61	0.56
	40	4	17	8.55	12.67	9.16	0.55
	36	2	43	8.35	12.13	8.86	0.56
	32	0	48	8.65	12.67	8.96	0.58
Delicious	[b]		—	12.15	12.40	9.70	0.23
Yakima, Wash.	85	30	8	9.60	12.84	11.04	0.20
1923–24	70	21	8	9.25	13.20	10.82	0.21
	60	16	8	9.25	13.24	10.56	0.20
	50	10	13	9.60	13.28	10.72	0.21
	40	4	20	9.50	13.04	10.56	0.29
	36	2	49	9.40	13.40	11.42	0.23
	32	0	77	9.60	13.12	11.46	0.20
Baldwin	[b]		—	16.60	11.46	7.32	0.75
Rosslyn, Va.	85	30	8	9.75	12.30	9.20	0.59
1923–24	70	21	8	9.80	11.76	7.66	0.65
	60	16	10	10.20	12.34	7.69	0.67
	50	10	19	9.90	12.44	7.46	0.74
	40	4	43	10.80	12.40	7.96	0.65
	36	2	85	9.80	12.68	8.22	0.65
	32	0	145	10.70	12.36	8.14	—

[a] At picking.
[b] After removal from 32°F. storage.

In some plant products death may result from the result of lack of respirable materials. Even in the apple it has been reported by one worker that death followed the exhaustion of sucrose.[157] It would

[157] D. Haynes and H. K. Archbold, *Ann. Botany, 42,* 965 (1928).

seem doubtful, however, that death of the apple fruit was due to lack of sugars *per se*. The senior author has noted that there may be as much as 8% of total sugars left in apple fruits when they were far past the state of marketability. Of course, the question arises again here as to when an apple is really dead—that is, death may occur long after the state of marketability has been passed.

Effect of Temperature on Sugar Changes. As might be expected, lowering the temperature of the apples slows down the rate of sugar loss. This effect of temperature on sugar changes may be seen in Table 15. It should be noted in Table 15 that apples of the same degree of firmness were compared. A lowering of the temperature results in retardation in the loss of all the component sugars (glucose, fructose, sucrose).[158,159] It is very difficult, however, always to correlate storage treatments with sugar changes. For example, small temperature differences may not result in discernible sugar changes.[160]

Effect of Carbon Dioxide and Oxygen Level on Sugar Changes. In general, it may be said that lowering the oxygen content and raising the carbon dioxide content of the atmosphere around apples will slow down sugar losses in storage.[161,162] Attempts to correlate small differences in storage atmosphere composition with sugar changes have been unsuccessful, however.

Effect of Ethylene on Sugar Changes. Addition of ethylene to the storage atmosphere accelerates the respiration rate of preclimacteric apples and hence speeds up the loss of sugar from the apple fruit.[163] Since this gas does not affect postclimacteric fruit it is doubtful if it would have any effect on the sugar content of such fruit. While sugar losses may be accelerated by the use of ethylene there may be an actual increase in the rate of starch hydrolysis immediately after picking. This is reflected in an increased percentage of sugar as a result of ethylene treatment during the early storage life of the fruit.[164] In figure 21 it will be noted that the use of ethylene resulted in an increase in sugar in Gravenstein apples at 50°F. (10°C.) and

[158] D. Haynes and H. K. Archbold, *Rept. Food Inv. Board., 1928,* 78 (1929).
[159] D. Haynes and H. K. Archbold, *ibid., 1927,* 122 (1928).
[160] J. R. Magness, H. C. Diehl, M. H. Haller, W. S. Graham, D. B. Carrick, F. S. Howlett, R. E. Marshall, H. H. Plagge, and G. H. Raleigh, *U. S. D. A. Bull., 1406,* 1926.
[161] E. V. Miller and C. Brooks, *J. Agr. Research, 45,* 449 (1932).
[162] E. V. Miller and O. J. Dowd, *ibid., 53,* (1936).
[163] R. B. Dustman, *Plant Physiol., 9,* 637 (1934).
[164] F. W. Allen, *Hilgardia, 6,* 381 (1932).

a decrease at 70°F. (22°C.). This was probably due to the fact that respiration was more rapid at the higher temperature and more sugars were consumed. At 50°F. (10°C.) the respiration rate was slower

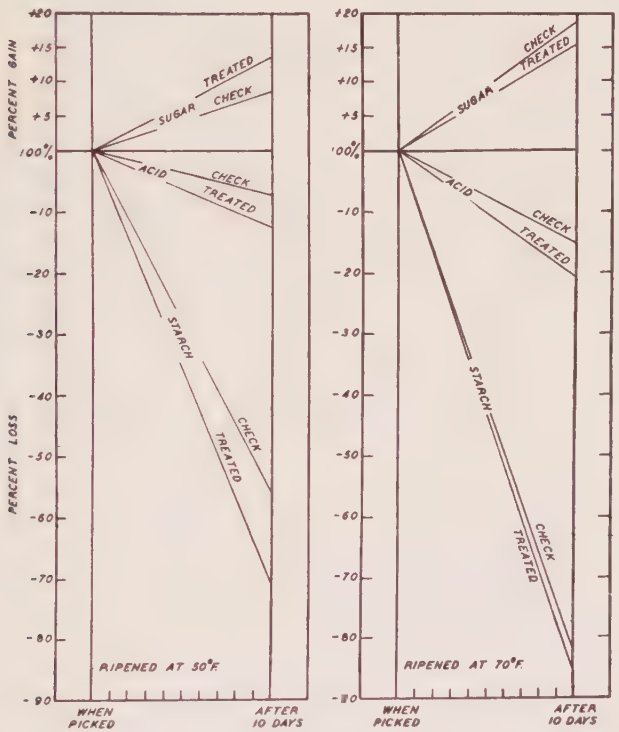


Fig. 21. Effect of ethylene treatments ("treated") on gain or loss in starch, total sugars, and total acids in Gravenstein apples after 10 days ripening at 50°F. (10°C.) and 70°F. (22°C.). The values given are in percentage of the amounts of these materials present at harvest time.[164]

than at 70°F. (22°C.) and the net increase in sugars was due to conversion of starch to sugar (which more than compensated for respiration losses).

2. POLYSACCHARIDES

Starch. It has already been indicated that if any starch remains in the fruit after harvest, it is rather quickly hydrolyzed into sugars.[165]

[165] W. D. Bigelow, *et al., U. S. D. A. Dept. Chem. Bull., No.* 94, 1905.

The rate of this hydrolysis depends upon the temperature of the fruit. Ethylene additions may also accelerate this breakdown of starch.[164] High carbon dioxide levels or low oxygen levels in the storage atmosphere would presumably retard the normal starch hydrolysis.

Pectin. It was pointed out in Chapter V that the cells of the apple flesh seem to be "cemented" together with some insoluble pectin compound. As the apples ripen and mature following harvest the cementing action is reduced and the cells become less firmly united to each other. This softening in the fruits is accompanied by a change from insoluble to soluble pectin. This correlation between softening and pectin changes is much closer following harvest than it is before

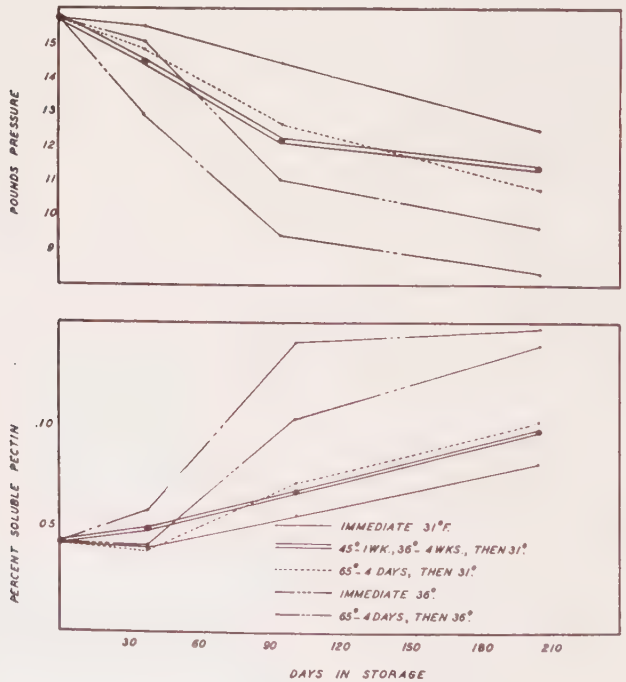


Fig. 22. Changes in firmness or pressure test (above) and soluble pectin (below) in Delicious apples as effected by various handling and storage practices.[167]

harvest. There is a good correlation between pectin changes in apples with pressure test readings. See Chapter VII for a discussion of the use of the pressure tester. Figure 22 illustrates this correlation between pressure test and soluble pectin increases in fruits given various postharvest treatments.

When apples become mealy or overmature there is a breakdown of the soluble pectin components into nonpectic ones. This means then that following harvest there is a gradual increase in soluble pectin with a corresponding decrease in insoluble pectin or protopectin. The amount of total pectin substances remains fairly constant following harvest until the apples become overripe and mealy; then there is a decrease in amount. It is during this time that the soluble pectic materials are being transformed into nonpectic materials.[166]

Storage *temperature* can be rather easily correlated with pectin changes in apples following harvest. There is considerable evidence that low storage temperatures retard the normal increase in soluble pectin[167] (see Figure 22). Haller has shown the striking relationship between storage temperature and the time required to reach a given pressure test and a given pectin content of Jonathan apples:[168]

TABLE 16. Relation between Changes in Firmness and Pectic Constituents of Stored Jonathan Apples[168]

Stored at		Days in storage required to reach		
°F.	°C.	Pressure test of 10 lbs.	Insoluble pectin content of 0.385%	Soluble pectin content of 0.195%
32	0	100	100	100
39	4	42	44	51
50	10	29	27	31
59	15	16	15	19

The nature of the *atmosphere* may have considerable effect on the transformation of pectic substances in apples during storage. Controlled atmosphere storage (high carbon dioxide and low oxygen

[166] M. H. Carré, *Biochem. J., 16,* 704 (1922).
[167] F. Gerhardt and E. Smith, *Proc. Wash. State Hort. Assoc., 41st Ann Meeting, 1945,* 1 (1946).
[168] M. H. Haller, *J. Agr. Research, 39,* 739 (1929).

levels) has been found to retard the normal pectic changes.[169,170] This probably is one of the main explanations why controlled atmosphere storage fruit is firmer upon removal from storage than fruit stored in air. One of the striking effects of controlled atmosphere storage is its residual effect (see page 149). It has been found that pectin changes do not occur as rapidly as one might expect upon removal of apples from controlled atmosphere storage to room temperature.[170] This does not necessarily mean that high carbon dioxide and low oxygen atmospheres necessarily affect the enzymes that may be responsible for protopectin breakdown. The enzymes assumed to be responsible for the pectic changes in apples could not be found.[171] *Ethylene* in the storage atmosphere has been found to stimulate the normal pectic changes in preclimacteric apples.[172]

For a more complete discussion of pectin changes in apples the reader is referred to a book which refers more specifically to pectin in fruits.[173]

Cellulose. Cell wall materials of the cellulose type seem to remain fairly constant during the storage of the apple.[174]

Hemicelluloses. This fraction decreases slowly in amount during storage.[174a]

Pentosans. There seems to be a gradual decline in the percentage of pentosans in apples as they ripen after harvest.[165]

Dextrins. By the time Grimes Golden apples were harvested, they were free of dextrins.[54]

C. Acids

The types of acids found in apples and their importance have been discussed in Chapter V. Acidity determines in part the eating quality of the fruit. For best eating quality apples should have some degree of acidity and yet not be too acid. The technologist or processor is interested in apple acidity because of its effect on apple products.

After apples have been harvested there is a decline in total titratable acidity.[157,160] Just what happens to these acids is not known.

[169] R. M. Smock and F. W. Allen, *Proc. Am. Soc. Hort. Sci.*, 35, 184 (1937).
[170] A. Van Doren, *ibid.*, *37*, 453 (1939).
[171] J. H. Griffin and Z. I. Kertesz, *Botan. Gaz.*, *108*, 279 (1946).
[172] E. Hansen, *Science*, *86*, 272 (1937).
[173] Z. I. Kertesz, *The Pectic Substances.* Interscience, New York, 1951.
[174] H. K. Archbold, *Ann. Botany*, *39*, 109 (1925).
[174a] G. Krotkov and V. Helson, *Can. J. Research*, *24*, 126 (1946).

It is presumed that they serve as at least a partial substrate for respiration along with sugar.[160] There is a small increase or rise in *p*H (*i.e.*, fruit gets less acid) after harvest.[175,176]

Effect of Temperature on Acidity Changes. Lowering the temperature of the apple results in a retardation of the acid loss in apples.[160] Hence, the cold storage of apples slows down the normal loss in acidity. The effect of storage temperature on acidity losses in apples is shown in Table 15.

Effect of Storage Atmosphere on Acidity Changes. The senior author (Smock) has found in unpublished work that raising the carbon dioxide level or lowering the oxygen level in the storage atmosphere would slow down normal acidity losses. It was impossible, however, to correlate small oxygen level differences with acidity losses.

Effect of Ethylene. Ethylene additions to the atmosphere around apples that are in the preclimacteric condition result in more rapid losses in acidity.[164]

Relation of Acidity to Storage Life of Apples. A number of experimental studies have attempted to correlate acidity losses or absolute amount of acidity with various physiological disorders of the apple and its storage life. In one English study it was reported that high acidity and a slow rate of acidity loss were conditions favoring physiological breakdown in storage.[177] Another study purported to show that the ratio of total acids to dissociated acids determined the keeping quality of fruit in storage.[178]

It has been shown that the acid content of apples was correlated with the amount of Jonathan spot occurring during storage. There was more Jonathan spot on samples of apples entering storage with a low acidity and on those apples which lost the least total acid during storage.[179] These same authors reported that there was less soggy breakdown in apples in storage when the loss in total acid during storage was small. The question that arises here is whether the amount of acidity and the rate of loss of acids was the cause of these storage troubles or merely accompanied the real causal factors.

[175] J. S. Caldwell, *U. S. D. A. Tech. Bull.*, 402, 1934.
[176] F. Kidd and C. Hanes, *Rept. Food Inv. Board, 1936*, 133 (1937).
[177] D. Haynes, *Ann. Botany, 39*, 77 (1925).
[178] M. S. Dutoit and J. Rayneke, *Union S. Africa Univ. Stellenbesch. Bull.*, 118, 1933.
[179] H. H. Plagge and F. Gerhardt, *Iowa Agr. Expt. Sta. Research Bull.*, 131, 1930.

D. Nitrogen Compounds

The *total nitrogen* content of apples does not change very much if at all after harvest; there is a marked change in the protein nitrogen fraction, however.[180,181] Following harvest there is a definite increase in the protein nitrogen. This rise in percentage of protein nitrogen (as percentage of total nitrogen) follows the respiratory rise or climacteric, that is, the peak of protein percentage is reached shortly after the climacteric peak is attained. While the protein nitrogen is increasing the *soluble nitrogen* fraction is decreasing.[181] This probably means that proteins are being synthesized from the soluble nitrogen components (see Figs. 23 and 24).

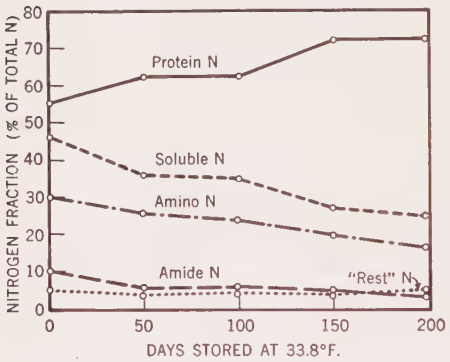


Fig. 23. Changes in the nitrogen fractions of Bramley's Seedling apples during storage at 33.8°F. (1°C.).[181a]

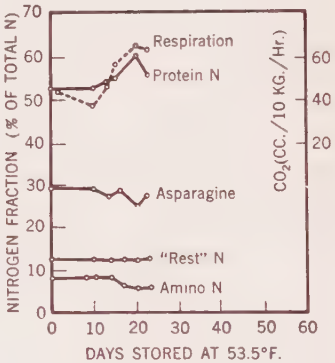


Fig. 24. Changes in the soluble nitrogen fractions of Bramley's Seedling apples during the respiratory climacteric at 53.5°F. (12°C.).[181b]

Factors Affecting Nitrogen Changes. When preclimacteric fruit is treated with ethylene, there is an induction of the protein increase in apples.[182] This means that ethylene stimulates not only respiration but also changes in the nitrogen fractions in the apple. The increase in protein nitrogen can be delayed by the use of carbon

[180] H. K. Archbold, *Ann Botany, 39,* 97 (1925).
[181] A. C. Hulme, *Rept. Food Inv. Board, 1935,* 126 (1936).
[181a] A. C. Hulme, *Rept. Food Inv. Board, 1932,* 75 (1933).
[181b] A. C. Hulme, *ibid., 1936,* 126 (1937).
[182] F. Kidd, C. West, and A. C. Hulme, *ibid., 1938,* 119 (1939).

dioxide atmospheres around the fruit held in storage[182] (see Fig. 25 below).

Relation of Nitrogen Content to Storage Life of Apples. Since the protein nitrogen curve follows a trend similar to that of the respiratory one, changes in this fraction can be followed as an index

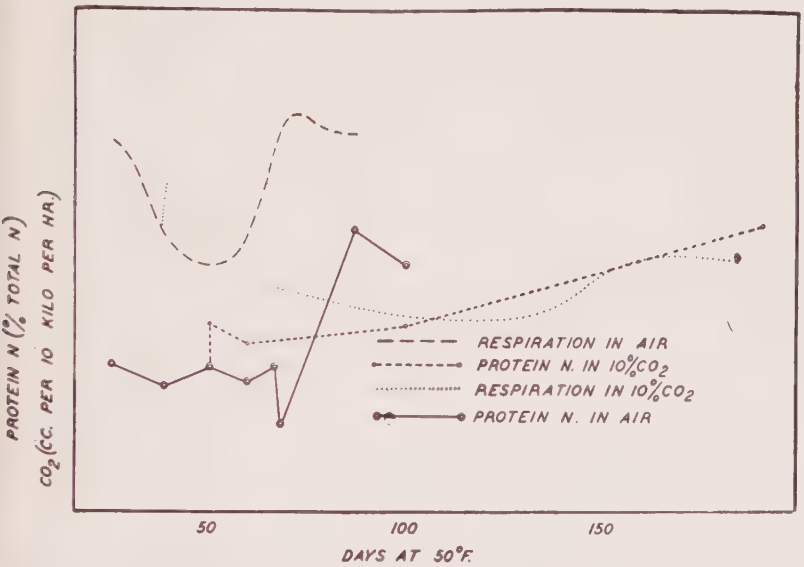


Fig. 25. The relation of respiration rate and protein nitrogen changes in Bramley's Seedling apples in air and in 10% carbon dioxide at 50°F. (10°C.).[182]

of the effect of various storage treatments. Since the changes in protein nitrogen are not as great in magnitude as respiratory differences, they would not seem as reliable a measure of ripening rate.

Attempts to correlate the content of total nitrogen in apple fruits with keeping quality of apples in storage have given conflicting results. Several reports from England have associated poor keeping quality in storage with high nitrogen content of the fruit.[180,181,183] A study has shown a straight-line relationship between protein content

[183] A. C. Hulme, *Ann. Rept. East Malling Research Sta. Kent 1936,* 185 (1937).

per cell and respiration rate[184] (see Fig. 26). This means that as the protein content per cell increases the respiration or living rate is proportionally more rapid. Work done in Ohio has indicated that there was no relation between total nitrogen content and keeping quality of the fruit.[185] This conflicting evidence may be partly explained by the fact that different varieties in different locations were

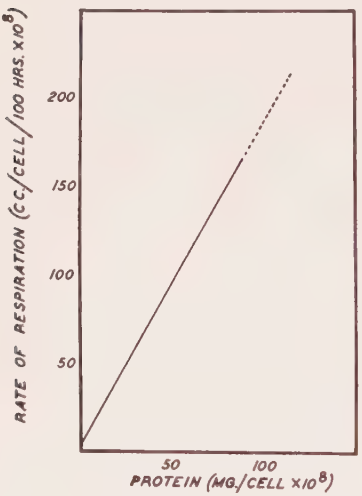


Fig. 26. Relation of respiration rate per cell and protein content per cell in Bramley's Seedling apples.[184]

employed. Then too, such studies should concern themselves with identical nitrogen levels in the fruit to make the evidence comparable. Work done in New York State has shown that with McIntosh apples there was no effect of nitrogen fertilization on keeping quality unless the amounts of leaf nitrogen were actually increased as a result of fertilization. When different leaf nitrogen levels were attained as a result of fertilization of the soil, there was strong suggestion of reduced fruit firmness and lessened ground color with the higher nitrogen application.[186] Effects of different nitrogen levels on actual respiration rate are discussed under Respiration.

[184] A. C. Hulme and W. H. Smith, *Rept. Food Inv. Board, 1938,* 127 (1939).
[185] J. H. Gourley and E. F. Hopkins, *Ohio Agr. Expt. Sta. Bull.,* 479, 1931.
[186] R. M. Smock and D. Boynton, *Proc. Am. Hort. Soc., 45,* 77 (1944).

E. Minerals

The importance of minerals in apples was discussed in the last chapter. On a dry-weight basis there are no marked variations in the ash or mineral content of apples after harvest. On a fresh-weight basis an apparent increase in percentage of minerals has been found because of the loss of water.[187] The fact that the mineral constituents do not change in amount after harvest is understandable when one remembers that they are not consumed in the life processes of the fruit.

Relation of Mineral Content to Storage Life of Apples. There have been some attempts to correlate the mineral constituents of apples with their potential storage life. For example, one investigator claimed that long keeping of apples was associated with high potassium and phosphorus in the fruit.[187] Other workers have found no correlation between mineral content of the fruit and potential storage life.[188,189] It is quite possible that a really potassium-deficient fruit might behave differently in storage than a normal fruit, yet it has been pointed out that although high potassium fruits may keep better than low potassium fruits at low temperatures, just the reverse may be true at high temperatures.[190] It may be concluded then in the light of our present knowledge that there is no clear-cut relation between mineral composition and length of storage life of apples.

F. Fats, Oils, and Waxes

It was pointed out in the last chapter that the waxy coating of apples consisted of ursolic acid, oily fraction, and total ether-soluble extract. During the postharvest period, all of these constituents increase in amount but the oily fraction increases at a faster rate than the ursolic acid.[191] This shift or change in the amount of oily fraction probably accounts for the increasingly greasy feeling of many varieties after they have ripened for some little time after harvest (see Fig. 27).

[187] J. W. Brown, *Ann. Botany, 43,* 817 (1929).
[188] E. S. Degman and J. H. Weinberger, *Maryland Agr. Expt. Sta. Bull.*, 366 (1934).
[189] E. F. Hopkins and J. H. Gourley, *Ohio Agr. Expt. Sta. Bull.*, 519, 1933.
[190] T. W. Wallace, *First Imp. Hort. Conf.*, Pt. III, 9 (1931).
[191] K. S. Markley and C. E. Sando, *J. Agr. Research, 42,* 705 (1931).

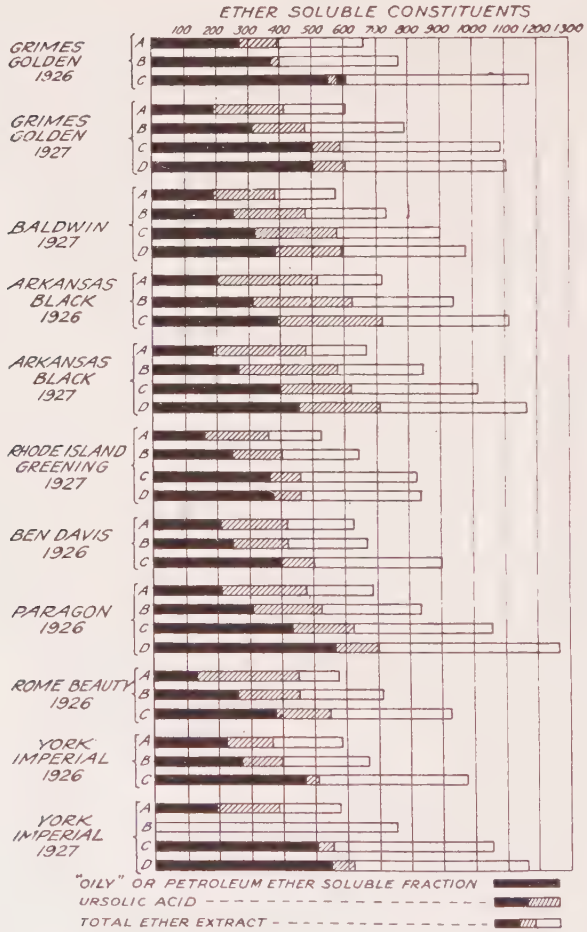


Fig. 27. Progressive changes in the waxlike constituents of apples during growth and storage expressed as milligrams per 100,000 square millimeters of fruit surface. *A*, *B*, *C*, and *D* refer to the "early," "medium," "mature," and "storage" stages.[191]

While no specific work has been done on the effect of various storage factors on the fats, oils, and waxes on apples, it would seem safe to conclude that in general any storage condition which retards ripening would probably slow down the changes in these constituents.

G. Color Compounds

The chemical constituents of apples responsible for coloration were discussed in the last chapter. It was pointed out that no red coloration takes place during storage. Methods of developing red coloration immediately after harvest were also discussed in that chapter. During the ripening period following harvest, there is an increase in the amount of ground color (except for the all-red fruits.) Any storage condition which will check ripening will inhibit this normal green to yellow change.

H. Enzymes

Oxidases. As fruits ripen after harvest there is little variation in the trend of oxidase activity. However, in fruits which are picked when fully mature there is usually a lower oxidase activity than in fruits picked when less mature.[192] During storage one *variety* may have a considerably higher oxidase activity than another. Yellow Newtowns have a higher activity than Golden Delicious, Jonathan, and Delicious. There seems to be no correlation between oxidase activity and length of storage life since Yellow Newtown is a long-lived apple in storage and yet it has a higher oxidase activity than Jonathan and Delicious.[192]

The effect of *temperature* in storage on oxidase activity is not clear-cut. At any rate the effect of this factor is not at all striking. In one study it was reported that activity was little different in apples stored at 32°F. (0°C.) as compared with those stored at 36°F. (2°C.).[193]

Catalase. There seems to be little change in catalase activity in apples after harvest although in some varieties there is a suggestion of increasing activity as the fruits become ripe. Fruit maturity at the time of harvest seems to have some effect on catalase activity during storage. Fruits harvested when fully matured usually showed a higher catalase activity in storage than did fruit picked when less matured.[194]

Varieties differ in their catalase activity during storage but there seems to be no direct correlation between this factor and length of

[192] B. D. Ezell and F. Gerhardt, *ibid., 56,* 365 (1938).
[193] B. D. Ezell and F. Gerhardt, *ibid., 60,* 89 (1940).
[194] B. D. Ezell and F. Gerhardt, *ibid., 65,* 453 (1942).

keeping or respiration rate.[194-196] Delicious shows somewhat higher activity during storage than do Yellow Newtown, Golden Delicious, and Jonathan (Fig. 28).

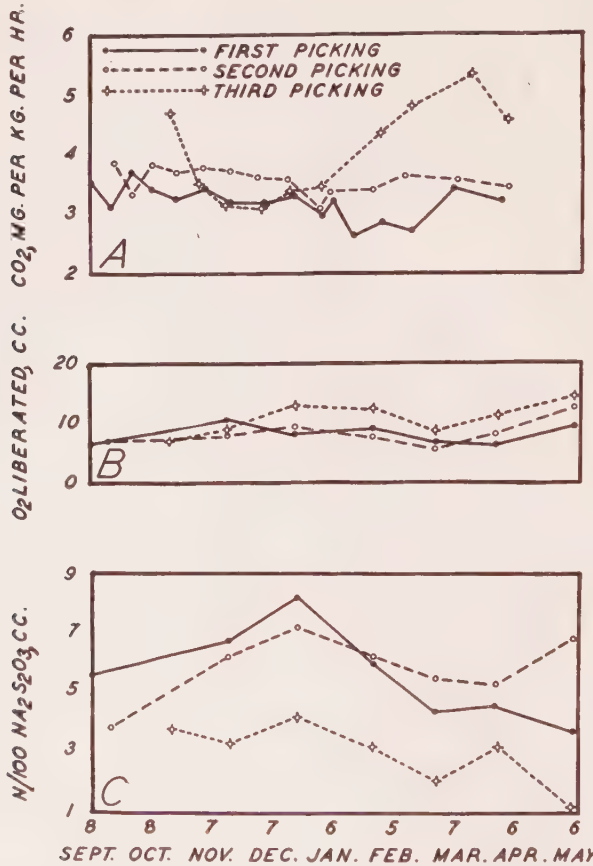


Fig. 28. Effect of maturity at harvest time on the rate of respiration (*A*), catalase activity (*B*), and on oxidase activity (*C*) of Jonathan apples during cold storage at 32°F. (0°C.).[194]

The effect of *temperature* of storage on catalase activity in apples is not clear. It has been reported that catalase activity at 32°F. (0°C.)

[195] B. D. Drain, *Botan. Gaz. 82*, 183 (1926).
[196] P. Harding, *Proc. Am. Soc. Hort. Sci., 27*, 37 (1930).

was higher than in similar apples held at 77°F. (25°C.).[195] It has also been reported that catalase activity was higher in Grimes Golden apples at 30°F. (−1°C.) than at 36°F. (2°C.). This observation may have been associated with the fact that these apples later developed soggy breakdown and the high catalase activity was noted just prior to the onset of breakdown.[196]

Delayed storage at higher temperatures followed by storage at low temperatures resulted in higher catalase activity in Grimes Golden apples than prompt storage.[196]

Nitrogen fertilization in the orchard has been found to increase catalase activity not only in fruits as they mature on the tree but also in fruits in storage at different temperatures.[185,196]

It has been found that relatively short periods of *freezing* (followed by thawing) would increase catalase activity but that extended periods of freezing would reduce it.[197]

I. Vitamins

1. VITAMIN A

None of the fruits are very rich in the precursor of this vitamin (carotene) as are fish oils, dairy products, and green vegetables. Apples, however compare favorably with the other fruits in their amount of vitamin A precursor. Apples have been shown to have only slightly less vitamin A precursor than orange juice and considerably more than pears and a little less than bananas.[198] In many plant tissues this vitamin is associated with the yellow or orange color of the tissues. Yet white-fleshed apple varieties seem to have no less vitamin A precursor than the yellow-fleshed ones.[199] The peel of Delicious apples has been shown to have five times as much vitamin A precursor as the flesh.[200] Highly colored Delicious apples seemed to have more of this vitamin precursor than poorly colored ones.[200]

The vitamin A precursor content of apples differs among varieties. The variety Rome Beauty has 42 Sherman units of this vitamin precursor per ounce whereas Yellow Newtown has 119 units.[200] An average value for "apples" has been given as 80 units.[200a]

[197] D. B. Carrick, *Cornell Univ. Agr. Expt. Sta. Mem.*, 122, 1929.
[198] E. N. Todhunter, *Wash. Agr. Expt. Sta. Pop. Bull.*, 152, 1937.
[199] M. T. Potter, *J. Nutrition*, *6*, 99 (1933).
[200] E. N. Todhunter, *Wash. Agr. Expt. Sta. Bull.*, 375, 1939.
[200a] W. V. Cruess, *Fruit Products J.*, *19*, 230 (1940).

2. VITAMIN B COMPLEX

The vitamins usually listed as part of the B complex (thiamin, niacin, choline, and pantothenic acid) are found in only small quantities in the fruits. Whole grain cereals and vegetables are much better sources. Therefore the possible contribution of apples to the nutritional needs of humans is small. In days when components of the B complex were not known, Rome Beauty was reported as having 16 such units per ounce and Northern Spy 7 as compared with a daily requirement of an adult 200–400 units.[200a]

In studies on the thiamin content of "apples" the amount found varied from 0.010 to 0.69 milligram per 100 grams of flesh.[200b,200c] The content differed among the varieties analyzed. In another study on the vitamin B complex in apples the following amounts of the various components were found in terms of milligrams per 100 grams of fresh apple; thiamin 0.096; nicotinic acid 0.081; pantothenic acid 0.60; pyridoxine 0.026; biotin 0.0009; inositol 24.0; folic acid 0.008.[200d]

3. VITAMIN C

This vitamin (ascorbic acid) is much more abundant in apples than is any other one. While very few of the apple varieties are very rich in this vitamin, it is true that by eating enough apples per day a human could get his requirement of this vitamin. By eating two Washington Winesaps or five Delicious per day an adult could get his full daily requirement of ascorbic acid.[198]

The role which this vitamin may play in fruit physiology is not known. It has been shown with apple tissue studies that ascorbic acid can accomplish the change of protopectin to pectin, but whether this material actually is involved in fruit softening in whole fruit is not yet known.[201] As will be noted in the section on the effect of temperature in storage (below) ascorbic acid usually diminishes during storage. Yet whether it decreases or actually increases seems to be dependent in part on the age of the fruit. It has been found that the capacity for actual synthesis in the fruit diminishes as the ratio of dehydroascorbic acid to ascorbic acid decreases in the maturation

[200b] R. L. Lane, E. Johnson, and R. R. Williams, *J. Nutrition, 23,* 613 (1942).
[200c] American Can Co. Research Dept., *The Canned Food Reference Manual.* American Can Co., New York, 1943.
[200d] V. H. Cheldelin and R. J. Williams, *Univ. Texas Publ., No. 4237,* 1942.
[201] J. H. Griffin and Z. I. Kertesz, *Botan. Gaz., 108,* 279 (1946).

process on the tree. It was shown that in immature Bramley seedling apples stored at 37.4°F. (3°C.) there was actually a synthesis of ascorbic acid during storage.[202] Whether storage temperature as well as age of fruit may have some influence on this synthesis is not clear, although it has been reported that ascorbic acid was lost from apples at "high storage temperatures" but actually increased at 31°F. (−0.5°C.) to 30.2°F. (−1°C.).[203]

There seems to be some controversy as to the presence of an ascorbic acid oxidizing enzyme in apple tissue. One group of workers has reported that no such enzyme is present in apples and that the phenolases are responsible for ascorbic acid oxidation in apple tissue.[203a] Another worker has reported that an enzyme which will oxidize ascorbic acid has been isolated and that no phenolases were found.[203b] These contradictory results are probably due to differences in technique of extraction of the "enzyme."

Most of the ascorbic acid in apples is in the peel or just under the peel and decreases as one samples nearer the core.[203c] In Golden Delicious it has been found that less than half of the total vitamin C was found in the peeled fruit.[203d] Baldwin was found to have four times as much ascorbic acid in the epidermis as in the flesh just underneath and six to ten times as much in the epidermis as in flesh near the core.[203e] Bramley Seedling was found to have six times as much ascorbic acid in the peel as in the flesh.[204] Twice as much ascorbic acid has been found in the red peelings of apples as in the green peelings from the same fruits.[205]

Varieties of apples differ widely in their amount of ascorbic acid although the average amount is considerably less than that in tomatoes or citrus fruit. The average content of ascorbic acid in 80 German varieties was 13.4 mg. per 100 grams of tissue (including the peel).[206] One variety of apples, Calville Blanc, has been found to have as much

[202] C. West and S. S. Zilva, *Biochem. J., 83,* 105 (1944).
[203] L. Scupin, *Gartenbauwiss., 17,* 30 (1942).
[203a] S. W. Johnson and S. S. Zilva, *Biochem. J., 31,* 438 (1937).
[203b] F. M. V. Hackney, *Nature, 158,* 133 (1946).
[203c] E. Gross, *Gartenbauwiss., 17,* 500 (1943).
[203d] E. N. Todhunter, *Food Research, 1,* 435 (1936).
[203e] C. R. Fellers, M. M. Cleveland, and J. A. Clague, *Proc. Am. Soc. Hort. Sci., 29,* 93 (1932).
[204] S. S. Zilva, F. Kidd, and C. West, *Rept. Food Inv. Board, 1934,* 164 (1935).
[205] O. H. Keys, *New Zealand J. Sci. Technol., 24B,* 146 (1942).
[206] W. Mockel, J. Wolf, and V. Degen, *Gartenbauwiss., 17,* 176 (1942).

TABLE 17. Ascorbic Acid Content of Some Apple Varieties

Variety	Place grown	Ascorbic acid, mg. per 100 g.	Approximate rating as source of ascorbic acid
Arkansas	New York	10–15	Fair
Baldwin	New York	15–20	Good
Ben Davis	New York	10	Poor
Calville Blanc	New York	35–40	Excellent
Cortland	New York	8–11	Fair
Cox Orange	New York	6–19	Fair
Delicious	Washington	12	Fair
Delicious	New York	10–15	Fair
Duchess	New York	15–20	Good
Duchess	West Va.	15–20	Good
Esopus	New York	23	Good
Fameuse	New York	10	Poor
Golden Delicious	New York	13	Fair
Golden Delicious	West Va.	10–15	Fair
Golden Delicious	Washington	5	Poor
Gravenstein	New York	10–15	Fair
Grimes Golden	West Va.	10–15	Fair
Hubbardston	New York	10–15	Fair
Jonathan	West Va.	13	Fair
Jonathan	New York	11–17	Fair
Kendall	New York	5–7	Poor
King David	New York	7–19	Fair
Lobo	New York	3–6	Poor
McIntosh	New York	4	Poor
McIntosh	West Va.	7	Poor
North West Greening	New York	11	Fair
Opalescent	New York	23	Good
Red Astrachan	New York	10–15	Fair
Red Spy	New York	15–20	Good
Rhode Island Greening	New York	10	Poor
Rome Beauty	West Va.	7	Poor
Rome Beauty	Washington	5	Poor
Roxbury	New York	15–20	Good
Stayman	West Va.	10–15	Fair
Stayman	Washington	5	Poor
Sturmer Pippin	New York	29	Excellent
Tompkins King	New York	10	Poor
Turley	New York	10	Poor
Twenty Ounce	New York	15–20	Good
Wagener	New York	10–15	Fair
Wealthy	West Va.	8	Poor
Winesap	New York	10	Fair
Winesap	Washington	6	Poor
Winter Banana	New York	11–12	Fair
Yellow Newtown	New York	16	Good
Yorking	New York	9–13	Fair
York Imperial	West Va.	8	Poor

ascorbic acid as citrus fruit.[207] This is not a commonly grown variety in America, however. A survey of English varieties showed Yollington Mill to be the highest in ascorbic acid (34 mg. per 100 grams).[207a] The genetic character or characters responsible for high ascorbic acid content in apples seem to be transmissible by breeding,[207] that is, the progeny of a high ascorbic acid parent (or parents) in apple breeding seem to be high in this vitamin. Analyses of many apple varieties in America have been made for this vitamin[203d,203e,207] Table 17 indicates the range in ascorbic acid of some common varieties of apples grown in various places. Comparisons should probably not be made between results from place to place because of dissimilarity in methods of taking samples and determinations of this vitamin. Table 17 does indicate the relative ranking of some of the common varieties of apples, however. Of the common varieties of apples, Yellow Newtown is probably the richest source of this vitamin. Baldwin and Northern Spy are good sources whereas McIntosh is a very poor one.

Effect of Soil. The effect of soil type as such on this vitamin has not been found to be a measurable one.[208]

Effect of Fertilizers. In an English study it was found for one variety (King Edward) that high nitrogen fruits had less vitamin C than low nitrogen fruits. This effect was not observed in Bramley Seedling, however.[209] In one Washington study the greatest amount of this vitamin was found in unfertilized fruits[210] and in another no effect of fertilization was noted.[200] It should be noted, however, in the latter study that fertilization did not result in any increase in the nitrogen content of the fruits. While the evidence may seem somewhat contradictory on this point it might be concluded that if there is any effect of nitrogen fertilization it is to reduce the vitamin C content.

Effect of Leaf–Fruit Ratio. Winesap apples grown with one fruit per 10 leaves showed a higher vitamin C value than similar apples grown with 50 leaves per fruit. This would mean that small

[207] G. H. Howe and W. B. Robinson, *Proc. Am. Soc. Hort. Sci., 43,* 133 (1947).
[207a] A. Pollard, M. E. Kieser, and J. D. Bryan, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1945,* 200 (1946).
[208] M. F. Bracewell, F. Kidd, C. West, and S. S. Zilva, *Biochem. J., 25,* 138 (1931).
[209] M. F. Bracewell, T. W. Wallace, and S. S. Zilva, *ibid., 25,* 144 (1931).
[210] M. T. Potter and E. L. Overholser, *J. Agr. Research, 46,* 367 (1933).

fruits have more vitamin C per unit weight than large ones in this variety. No difference could be found in Delicious, however, as a result of varying the leaf–fruit ratio. No size difference was found in Delicious in this particular experiment (although thinning usually causes larger fruit in this variety). It was concluded by these Washington State workers that the leaf–fruit ratio affected this vitamin only through its effect on fruit size.[211] Small apples have a greater proportion of skin and it has been shown that the skin is considerably richer in vitamin C than the same weight of flesh tissue.

Other Orchard Factors Affecting Vitamin C. The type of *rootstock* on which trees were growing seemed to have no effect on vitamin C in apples in one study.[212] The *position* of the fruit in the tree seemed to have no effect on the amount of this vitamin in one study[198] although, as indicated before, the red peelings of apples seemed to have more ascorbic acid than the green peelings of the same apples.[204] *Time of harvest* has some effect on the amount of vitamin C in apples. It has been found that McIntosh and Wealthy apples gained in ascorbic acid for 42 days or more after the normal time of harvest.[206] Although the gain was slight, the apples continued to gain instead of lose this vitamin as they hung on the trees after their normal picking date. *Irrigation* had no effect on the ascorbic acid content of Rome Beauty apples but heavy irrigation of Delicious trees resulted in increased ascorbic acid content in the fruits.[200]

Effect of Storage on Vitamin C. The vitamin C content of apples is gradually lost during storage, the actual loss depending upon temperature, length of storage, variety, and atmosphere of the storage.[213] In a study with Delicious apples it was found that at 32°F. no vitamin C was lost during a six month storage period but that at 45°F. they lost one fourth of their original amount.[214] This variety has been kept for a year in storage at 45°F. (7°C.) with only a loss of 50% of the original vitamin C content.[201] The fruit would have been unmarketable at this time because of mealiness. Baldwin apples stored at 36°F. (2°C.) for nine months lost about one third of their original content of vitamin C. During the period in which they would normally be sold for consumption they lost no vitamin C.[214] Most

[211] E. L. Batchelder and E. L. Overholser, *ibid., 53,* 547 (1936).
[212] S. S. Zilva, F. Kidd, and C. West, *Rept. Food Inv. Board, 1932,* 91 (1933).
[213] M. C. Hessler and G. Craig, *Missouri Agr. Expt. Sta. Bull., 272,* 1929.
[214] C. R. Fellers, M. M. Cleveland, and J. A. Clague, *J. Agr. Research, 46,* 1039 (1933).

of the vitamin C loss during storage seems to take place in the peel.[215]

In a New Zealand study it was reported that controlled atmosphere storage (high carbon dioxide and low oxygen atmospheres) resulted in increased losses of this vitamin as compared to storage in air.[204] An English report has indicated the same finding for Bramley Seedling apples.[208] Unpublished work at Cornell with Yellow Newtown has indicated that low oxygen atmospheres in storage checked the normal loss of this vitamin. The variations in these results of controlled atmosphere would indicate that varieties may differ in their response and the exact nature of the atmosphere may have some bearing on the loss of this vitamin in storage.

4. RIBOFLAVIN

This vitamin, at times designated both as vitamin G and B_2, is present in apples in only minute quantities. There is about twice as much in apple tissue as in oranges, however.[198] Delicious has been found to contain 20 Sherman units per ounce, Balwin 16, and Northern Spy 10. About 600 Sherman units are needed by an adult human per day.[216] In another study it was reported that "apples" contained 0.018 milligram per 100 grams of tissue.[217]

J. Organic Emanations from Apples

1. ETHYLENE

In the early studies made on the gaseous emanations from apples it was found that this fruit gave off a gas (or gases) which caused striking morphological abnormalities in the potato. When the vapors of ripe apples were passed over potato sprouts it was found that abnormal radial growth and epinasty of the leaves resulted. Sprouting of potatoes (which had not yet started to grow) was prevented by passing such vapors over the potatoes.[218] Later it was shown that this gas was capable of stimulating the respiration or ripening rate of preclimacteric apples.[219 221] This particular gas in the emanations

[215] V. B. Fish, *Proc. Am. Soc. Hort. Sci., 43,* 73 (1943).
[216] E. P. Daniel and M. E. Munsell, *U. S. D. A. Misc. Pubs., 275,* 1937.
[217] V. H. Cheldelin and R. J. Williams, *Univ. Texas Pub. No. 4237,* 1942.
[218] O. H. Elmer, *Science, 75,* 193 (1932); *J. Agr. Research, 52,* 609 (1936).
[219] F. Kidd and C. West, *Rept. Food Inv. Board, 1932,* 55 (1933).
[220] F. Kidd and C. West, *ibid., 1934,* 11922 (1936).
[221] R. M. Smock, *Proc. Am. Soc. Hort. Sci., 40,* 187 (1942).

from ripe apples was found to cause a disorder in carnations known as "sleepiness" when these flowers were stored with apples.[222] This gas has now been definitely identified as ethylene (C_2H_4).[218,223–225]

Ethylene production of apples follows a curve very similar to that of the respiration curve. In McIntosh apples it was found that following harvest at about the optimum time for best keeping in storage the amount of ethylene steadily increased. The amount of ethylene evolved increased until it reached a peak. This peak followed the respiratory peak by about 5 days at 68°F. (20°C.). Following this peak there was a decline in production[226] (see Fig. 29). This same trend was found to be true in Astrachan, Red June, and Gravenstein apples.[227]

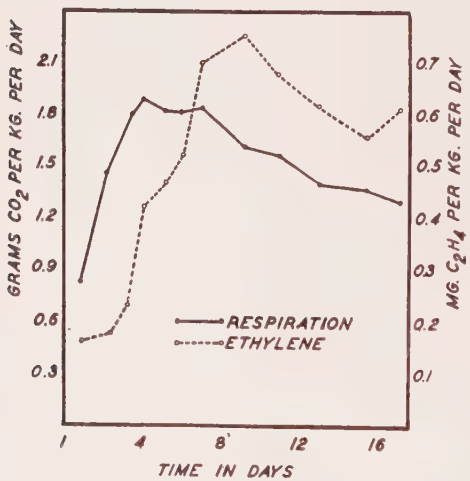


Fig. 29. Relation of respiration rate and ethylene production in McIntosh apples at 68°F. (20°C.).[226]

In general apple varieties which have a long storage life seem to produce less ethylene than those with a short storage life.[227,228] It has been found that one "apple" would produce about one cubic centimeter of ethylene during its lifetime.[226] This amount would

[222] D. V. Lumsden, *ibid., 39,* 392 (1942).
[223] R. Gane, *Nature, 134,* 11008 (1934).
[224] R. Gane, *Rept. Food Inv. Board, 1934,* 122 (1935).
[225] E. Hansen and H. Hartman, *Botan. Gaz., 101,* 403 (1939).
[226] R. C. Nelson, *Plant Physiol., 15,* 149 (1940).
[227] E. Hansen, *ibid., 20,* 631 (1945).
[228] R. C. Nelson, *Food Research, 4,* 173 (1939).

obviously vary with different varieties and with different sized fruits, but gives one an idea of the magnitude of ethylene production of apples. One bushel of apples has been found to produce from one to four cubic centimeters of ethylene per day at 32°F. (0°C.).[227]

Fig. 30. Normal tomato plant (left). Tomato plant in late stages of epinasty after exposure to emanations of seven ripe McIntosh apples for 24 hours (right).

In some instances ethylene has been known to accumulate in storage in quantities sufficient to injure apples.[221,229] When relatively high concentrations of naturally evolved ethylene accumulate in storage there is a typical spotting of the fruit. In the early stages this spotting may appear as a premature yellowing of the fruit in small areas, and in the late stages the spots may even turn brown.

The presence of ethylene from ripening apples can be detected

[229] F. Kidd and C. West, *J. Pomol. Hort. Sci.*, *16*, 274 (1938).

rather simply. Both tomato plants and growing pea seedlings are very sensitive to small concentrations of ethylene. A young tomato plant is sensitive to about one part of ethylene in 20 million of air. The vapors of two ripe McIntosh apples will cause a tomato plant to show severe epinasty (drooping of the leaves) within two or three hours at a high temperature (see Fig. 30). There have been a number of attempts to explain this epinasty effect of apple vapors on tomatoes. Some of the experimental work done on this subject indicates that the ethylene in the apple vapors causes the plant auxins (*i.e.*, growth regulators) to leak out of the phloem where they are normally conducted. This is presumed to cause lateral spreading of the auxins and hence unusual plant growth effects.[230] The marked epinasty which occurs on pea seedlings when exposed to apple vapors can even be used in a bioassay for ethylene.[231]

Effect of Storage Conditions on Ethylene Production. The *temperature* of the storage has a marked effect on the evolution of ethylene. The temperature coefficient or Q_{10} (*i.e.*, the number of times a process is increased in rate for each 10°C. or 18°F. rise) for ethylene production is from four to five. During the marked rise to a peak of ethylene production, the increase over minimal values is about 30 times whereas the respiratory increase during the climacteric rise is only about a twofold increase.[227] It has been found that an atmosphere of 10% carbon dioxide and 5% oxygen resulted in reduced ethylene production in King Edward apples.[231a]

Role of Ethylene in Fruit Physiology. It is not yet known what the role of this gas is in the physiology of apple fruits. Some workers have speculated that it was an intermediate product of respiration and merely accompanied this process. Others have postulated that it was an "autostimulant" for respiration. In other words small accumulations of ethylene in apple tissue were necessary for the climacteric rise in respiration to take place.

2. ESTERS

The odorous constituents of apples have been identified as being largely the amyl esters of formic, acetic, caproic, and caprylic

[230] G. Borgström, *Kgl. Fysiograf. Sällskap. Lund, Förh., 9,* No. 12 (1939).
[231] H. Pratt and J. B. Biale, *Plant Physiol., 19,* 519 (1944).
[231a] N. A. Potter and D. G. Griffiths, *J. Pomol., Hort. Sci., 23,* 171 (1947).

acids.[232,233] As yet no studies have been made on the changes in these fractions as the apples ripen. It might be presumed that the esters increase in amount as apples ripen. Certainly apples at harvest time are less odorous than fully ripe fruits.

3. ESSENTIAL OILS

Geraniol has been identified as another one of the odorous constituents of apples.[233] No studies have been made as yet on changes that may take place in this fraction of the organic volatiles of apples as they ripen.

4. ALDEHYDES

Acetaldehyde has been identified as one of the constituents of apple tissue.[232,234-236] The exact role of this aldehyde in apple metabolism is not yet fully understood. It has been suggested that it is an intermediate product of respiration.[237] Most workers who have studied acetaldehyde in apple tissue have concluded that it is present in normal apple tissue and that during senesence[238] or in low oxygen atmospheres[239] there may be accumulations. In apples severely affected with the scald disease, it has been found that there may be relatively large accumulations of acetaldehyde.[240,241] Whether these accumulations actually cause the scald or merely accompany the death of the epidermal cells is not known but the latter possibility seems more likely.

5. ETHYL ALCOHOL

Traces of ethyl alcohol have been found in normal apple tissue even though one thinks of this material as forming only in the presence of anaerobic conditions.[234,236] It is not likely, however, that quantities of this material will accumulate in the apple unless anaerobic conditions are in effect[239] or in late senescence.[238] When ethyl alcohol

[232] F. B. Power and V. K. Chesnut, *J. Am. Chem. Soc., 42,* 1509 (1920).
[233] F. B. Power and V. K. Chesnut, *ibid., 44,* 2938 (1922).
[234] J. C. Fidler, *Biochem. J., 28,* 1107 (1934).
[235] A. C. Hulme, *Rept. Food Inv. Board, 1933,* 70 (1934).
[236] E. V. Miller, *J. Agr. Research, 52,* 49 (1936).
[237] J. C. Fidler, *Rept. Food Inv. Board, 1935,* 115 (1936).
[238] M. Onslow, F. Kidd, and C. West, *ibid., 1928,* 31 (1929).
[239] M. Thomas, *Biochem. J., 19,* 927 (1925).
[240] F. Gerhardt, *J. Agr. Research, 64,* 207 (1942).
[241] M. Thomas, *Proc. First Imp. Hort. Conf.,* Pt. III, 98 (1931).

does accumulate in apple tissue it seems to act as a poison and depresses the respiration rate.[242] It is very likely that the off flavors that are encountered in fruits that have been stored too long or under anaerobic conditions, or are affected with physiological disorders (such as internal browning), may be due to the presence of ethyl alcohol or acetaldehyde or both.[240]

A trace of methyl alcohol has been found in apples but it was not clear whether this alcohol occurred as such in apples.[232]

6. TOTAL ORGANIC VOLATILES

While ethylene and acetaldehyde have been measured as specific volatile emanations from apples, most of the measurements on volatiles have been on "total organic volatiles." Measurement of total organic volatiles is done either by complete combustion or by absorption in sulfuric acid followed by oxidation with ceric sulfate. When the ceric sulfate method is used, ethylene is not included. Sulfuric acid will not absorb ethylene unless silver, nickel, or mercuric sulfates are added to the acid. Hence, any results that are reported should indicate the method of measurement of total organic volatiles. The ceric sulfate method is a more or less empirical one since one does not know the specific volatiles being measured and the results are not expressed on an absolute basis but rather as "milligrams of ceric sulfate reduced." While these measurements are valuable they would be more valuable if one knew what the various volatile fractions were. For example, the total quantity of volatiles of a given lot of apples might be found to be rather low and yet the specific fraction causing the scald disease might be relatively high.

Factors Affecting Production of Total Volatiles. The production of total volatiles (as measured by the ceric sulfate method) varies considerably depending upon a number of factors. *Variety* of apples is one important factor. McIntosh apples produce large quantities of volatiles but other varieties like Rhode Island Greenings produce relatively little. This may be one reason why exposure of apples of the latter variety to vapors of McIntosh results in increased scalding (see page 221). *Age* of the fruit determines in large measure

[242] F. Kidd and C. West, *Rept. Food Inv. Board, 1933*, 60 (1933); 60 (1934).

how much volatiles a given variety will produce.[243,244] The production of volatiles goes through a curve very similar to the respiration curve. The peak of volatile production follows the respiratory peak by several days at a relatively high temperature (see Fig. 31). *Tem-*

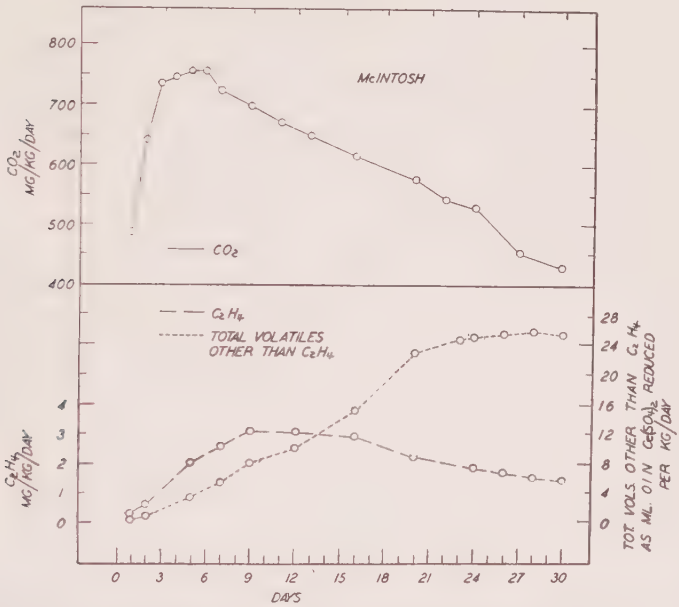


Fig. 31. Relation of respiration rate, production of ethylene, and production of total volatiles (excluding ethylene) in McIntosh apples held at 74°F. for 30 days after harvest, Harvested October 1, 1946.[244a]

perature exerts a profound effect on the production of total volatiles. It is commonly observed that warm apples are very much more aromatic than cold ones. It has been found that Golden Delicious apples produce almost twice as much total volatile materials at 36°F. (2°C.) as at 31°F. (—0.5°C.).[243] With McIntosh apples twice as much was produced at 40°F. (4°C.) as at 32°F. (0°C.).[244] It might be concluded that the Q_{10} of volatile production for these two varieties

[243] F. Gerhardt and B. D. Ezell, *J. Agr. Research. 58,* 493 (1939).
[244] F. W. Southwick, *ibid., 71,* 279 (1945).
[244a] C. R. Gross, *unpublished data,* Cornell University, 1947.

approached a value of four. There also seems to be a residual effect of temperature on volatile production. It has been found that McIntosh apples stored at 32°F. (0°C.) evolved less total volatiles when removed to a high temperature than did similar apples that had been stored at 40°F. (4°C.).[244] This finding may offer a clue as to why McIntosh apples held in cold storage never seem to develop their full

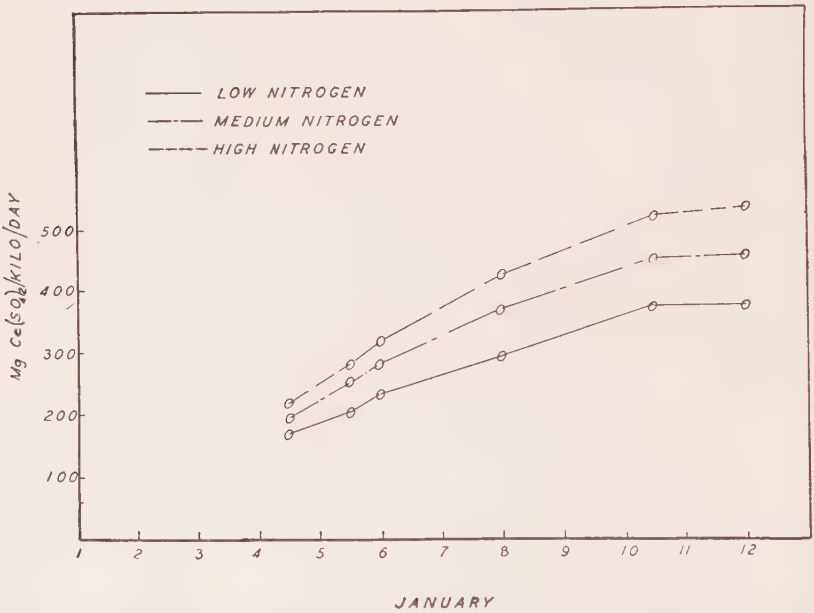


Fig. 32. Effect of differential nitrogen treatment in the orchard on the production of volatile materials from McIntosh apples at 74°F. (23°C.) after removal from storage at 32°F. (0°C.) in January.

aroma. The same thing has been observed in McIntosh apples held in controlled atmosphere storage as compared with storage in air.[244] While it is true that controlled atmosphere apples may not be as aromatic as apples of the same degree of ripeness held in ordinary cold storage, they are longer lived upon removal from storage and evolve volatiles over a longer period of time.

Composition of the atmosphere affects the production of odorous volatiles by apples in storage. An atmosphere of 5% oxygen and 10%

carbon dioxide reduced the production of odorous volatiles in King Edward apples.[244b]

Ethylene evolved by ripening apples has been found to stimulate the production of total organic volatiles by less ripe apples.[244] *Injury* to apple fruits has been found to increase the production of volatiles from apples.[243] Whether this fact has any significance from the standpoint of loss of aroma and hence of eating quality is not known. *Heavy nitrogen fertilization* has resulted in increased production of total volatile materials from McIntosh apples[245] (see Fig. 32). The possible effect of fruit *size* is not clear-cut but there is an indication that large apples produce more volatiles than smaller ones.[245]

K. Composition of Internal Atmosphere of Apples

One cannot consider the chemical composition of the apple or its physiology without some reference to the gases in the intercellular spaces. It has already been pointed out that there are many interlacing intercellular spaces in the parenchyma of the apple. In fact, about 25% of the volume of the apple fruit is composed of air spaces (in contrast with the potato with its densely packed cells with only 2% air space).

Water Vapor. Since the protoplasm of the apple flesh cells is largely water it is no wonder that there is considerable water vapor in the intercellular spaces. It is usually presumed that the intercellular relative humidity of an apple after harvest is 100%. It is probably slightly less than this although no measurements of relative humidity have been made. After the apple has become somewhat desiccated, following extreme shrivelling, the relative humidity may not, of course, be that high. The physiological implications of this water vapor in the intercellular spaces have been discussed under "transpiration."

Oxygen and Carbon Dioxide. A number of studies have been made on the oxygen and carbon dioxide contents of apple flesh. Most of these studies, however, have not differentiated between dissolved gases and those that existed in the free state in the intercellular spaces, that is, the analytical methods have usually been such that any dissolved oxygen or carbon dioxide in the cells would also be included.

One of the most important factors affecting the concentration of

[244b] N. A. Potter and D. G. Griffiths, *J. Pomol. Hort. Sci., 23,* 171 (1947).
[245] R. M. Smock, *Unpublished data,* Cornell Univ., 1945.

oxygen and carbon dioxide in the intercellular spaces of the apple is the *temperature* of the fruit.[246,248] It should be remembered that in ordinary air there is about 21% oxygen, about 0.03% carbon dioxide, very small amounts of certain rare gases, and the remainder is nitrogen. The cells of the apple fruit are actively respiring, and if the temperature is very high (*i.e.*, rapid respiration) oxygen cannot diffuse into the fruit as fast as it is being consumed. Hence under high temperature conditions (*i.e.*, 80–90°F.), the oxygen level may be relatively low. With Granny Smith apples it has been shown that at 44.6°F. (7°C.) the oxygen level was 17% but at 84.6°F. (29°C.) it was 2%. Temperature has a similar effect on carbon dioxide concentrations in the intercellular spaces, that is, this gas does not diffuse out of the fruit as rapidly as it is produced at high temperatures. With the same variety of apples, it has been shown that at 44.6°F. (7°C.) the carbon dioxide level was 2% and at 84.6°F. (29°C.) it was 17%.[248] It is interesting to note that at both of these temperatures, the total of the two gases was always less than 21% (normally, the summation of carbon dioxide and oxygen in air would be 21). This same observation is apparent from Table 18 with another study of

TABLE 18. Composition of Internal Atmosphere of Apples as Affected by Temperature[246]

Temperature		Oxygen, %	Carbon dioxide, %	Nitrogen, %
°F.	°C.			
34.6	1.4	14.2	6.7	79.1
40.8	4.3	12.9	8.9	78.7
51.8	11	10.7	12.2	77.1
68.0	20	5.5	17.2	77.3
86.0	30	3.2	21.4	75.4

apples held at different temperatures. At really low storage temperatures (*i.e.*, 34.6°F.) the summation is close to 21%, however.

There is a marked effect of the external atmosphere on the internal atmosphere of apple fruits.[247,248] In one study it was found that as the oxygen level of the surrounding atmosphere was dropped

[246] J. R. Magness, *Botan. Gaz., 70,* 308 (1920).
[247] F. Kidd and C. West, *Rept. Food Inv. Board, 1934,* 110 (1935).
[248] S. A. Trout, E. G. Hall, R. N. Robertson, Frances M. V. Hackney, and S. M. Sykes, *Australian J. Exptl. Biol. Med. Sci., 20,* 219 (1942).

from 20% to 12% the internal oxygen concentration in the apples dropped from 18 to 11%. In this study the temperature was held at 39.5°F. If the temperature had been higher the disparity between internal and external oxygen concentrations would doubtless have been greater.[248]

When apples are covered with a material like a *wax* emulsion or with a *plastic* material like Pliofilm there usually results a build-up in carbon dioxide and a lessening of the oxygen.[249–251] This is due to the fact that the diffusion rate of these gases is reduced. A completely impermeable material like heavy-weight Pliofilm may result in a build-up of 20% or more of carbon dioxide in the tissues of the fruit. In one study the calyx was completely closed over in Delicious apples by means of wax. This resulted in the oxygen level of the fruits falling to a lower level than if the calyx had not been closed over.[249] This would indicate that some of the oxygen gets into the tissues of the apple through the calyx tube instead of through the skin. The results did not indicate, however, that a very high percentage of the apple's oxygen gets into the fruit in that way.

Ethylene. This gas has been extracted from the internal atmospheres of apples and quantitatively determined. It has been found that whole, ripe Gravenstein apples had 0.038 milliliter per 100 grams of fruit. When slices of the fruits were analyzed the amounts found were somewhat lower, but this was probably due to leakage of the gas from the cut surfaces. Ripe Red June apples were found to have 0.012 milliliter of ethylene per 100 grams of whole fruit.[251a]

Resistance of Skin to Gaseous Diffusion. It is obvious that changes in the physical characteristics of the skin would make differences in the ease with which gases pass into or from the apple. The young or developing apple has been found to have comparatively little resistance to diffusion but as it matures on the tree and in storage diffusion becomes more difficult at least with regard to oxygen and carbon dioxide.[249] A formula has been prepared to express the resistance to diffusion presented by the skin of apples. The formulas used for the calculation of the resistances of skin per unit area to the passage of oxygen (r_o) and of carbon dioxide (r_c) are:

[249] F. M. V. Hackney, *Proc. Linnean Soc. N. S. Wales, 49,* 91 (1944).
[250] R. M. Smock, *Proc. Am. Soc. Hort. Sci., 33,* 284 (1936).
[251] H. A. Baghdadi and R. M. Smock, *ibid., 42,* 238 (1943).
[251a] B. E. Christensen, E. Hansen, and V. H. Cheldelin, *Ind. Eng. Chem., Anal. Ed., 11,* 114 (1939).

$$r_o = \frac{qO + 0.2\,qN}{qR} \text{ and } r_c = \frac{qC}{qR}$$

Where R is the rate of production of carbon dioxide in cc. given off per sq. cm. per unit of time, qR is the corresponding amount of oxygen absorbed, and qO, qN, and qC are the differences in concentrations of oxygen, nitrogen, and carbon dioxide, respectively, between the internal atmosphere of the fruit and the external atmosphere. Of course, these formulas give r_o and r_c in abritrary units.[249]

L. Respiration

A statement on the nature of respiration in the apple fruit was made in the last chapter. It will be recalled that the equation for respiration was $C_6H_{12}O_6 + 6O_2 \longrightarrow 6H_2O + 6CO_2 +$ energy (glucose + oxygen $\longrightarrow$ water + carbon dioxide + heat).

1. FACTORS AFFECTING RESPIRATION RATE AFTER HARVEST

Age of Fruit. It was pointed out in Chapter V that respiration rate is not constant for apples as they ripen. This is true even though they are held at a constant temperature. It was pointed out that just prior to the normal time of harvest there is a declining rate of respiration.

Following the minimum or low point on the respiration curve there is a rise in the respiratory rate. The rate increases until it reaches a peak which is then followed by a gradual decline. The rise in rate is called a "climacteric" rise and the peak is called the "climacteric."[252,253] To assign a climacteric or menopause to apples seems a little far-fetched but the term has now been widely accepted by investigators all over the world. While apples are declining in rate following the peak they are said to be in "senescence."[254] Apples after harvest are referred to as being "preclimacteric" or "postclimacteric" depending upon their position on the normal curve. While it is true that apples are normally picked after the respiratory rise has begun, they may be picked before or after this time, depending upon the variety and the purpose for which the fruits are to be used. For most

[252] F. Kidd and C. West, *Plant Physiol., 20,* 467 (1945).
[253] F. Kidd and C. West, *Proc. Roy. Soc. London, B106,* 93 (1930).
[254] F. Kidd and C. West, *Rept. Food Inv. Board, 1935,* 97 (1936).

purposes, apples would seldom if ever be picked in a "postclimacteric" condition. Figure 33 shows typical respiration curves for several varieties of apples.

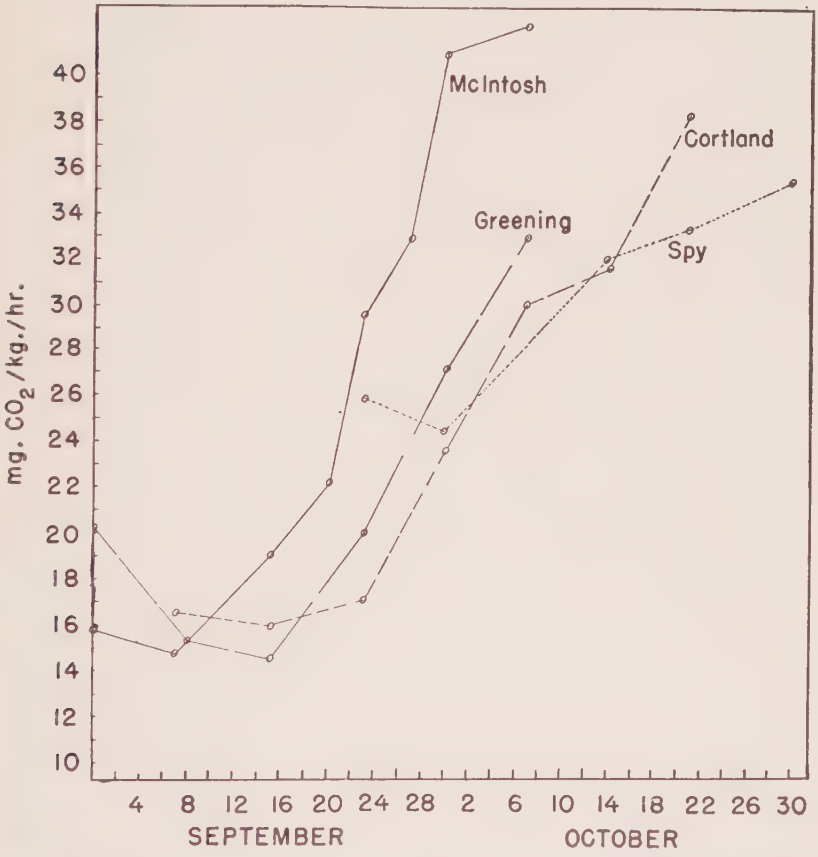


Fig. 33. Respiration rate of four varieties of apples picked at different dates in 1944 at 74°F. (23°C.). Each point on each curve is the respiration determination made 24 hours after each harvest date.

The actual magnitude of the respiratory rise in apples depends upon a number of factors. Variety, climatic conditions during the growing season, temperature of storage, and nature of the surrounding atmosphere in storage are some of the conditions that may cause

the peak to be higher in one case than in another. The rate of respiration of a variety like Duchess of Oldenburg may be three times as high as at the minimal value prior to harvest.[221] In other varieties like Jonathan[255] or Rhode Island Greening[256] the respiratory rise may be rather low, that is, the peak in rate is not much higher than the minimal value. Unpublished work at Cornell has shown that with a given variety the actual peak may be considerably higher in late-picked fruit than in early-picked fruit. This is especially true in a variety like Rhode Island Greening. In general the respiratory rise is much more evident at a high storage temperature than at low.[256] Of course, one would expect the peak to be higher at a high temperature, but we are referring here to the percentage rise over minimal values. Some varieties show no respiratory rise when stored continuously at a very low temperature (32°F.) or in controlled atmosphere storage. Nevertheless, when such apples are brought out of storage and held at a high temperature one can tell if they are pre- or post-climacteric. In other words, even though no *apparent* climacteric was evident during storage, the apples apparently underwent some such physiological change in state.

Not only does the total amount of carbon dioxide evolved by apples vary with age but also the respiratory quotient (CO_2 production/O_2 consumption). The respiratory quotient of one variety of apples varied from 1.0 to 1.25 at 40°F. (4°C.) depending upon the age of the fruit.[257]

Just what the full significance of the climacteric rise is does not yet seem to be fully appreciated. It would seem logical to expect that apples would keep longer in storage if they were picked in a pre-climacteric condition. So much of the potential life of the fruit is exhausted during the respiratory rise, it would seem reasonable to try to flatten out this normal rise or delay it by proper storage. Attempts have been made to correlate the proper time of harvest with position of the fruit on the respiratory curve. This point will be dealt with in detail in the discussion of determining fruit maturity. Attempts have been made to correlate the climacteric rise with the occurrence of certain storage disorders in the fruit. For example, it has been claimed that low-temperature breakdown in English apples

[255] M. H. Haller and J. M. Lutz, *Proc. Am. Soc. Hort. Sci., 34,* 173 (1937).
[256] R. M. Smock, *Cornell Univ. Agr. Expt. Sta. Bull.,* 799, 1943.
[257] F. Kidd and C. West, *Rept. Food Inv. Board, 1935,* 97 (1936).

occurred only when they were placed in storage while at the respiratory peak.[258] Attempts to make good correlations of this sort with disorders like soggy breakdown and soft scald in Grimes Golden and Jonathan have not been successful.[255,259]

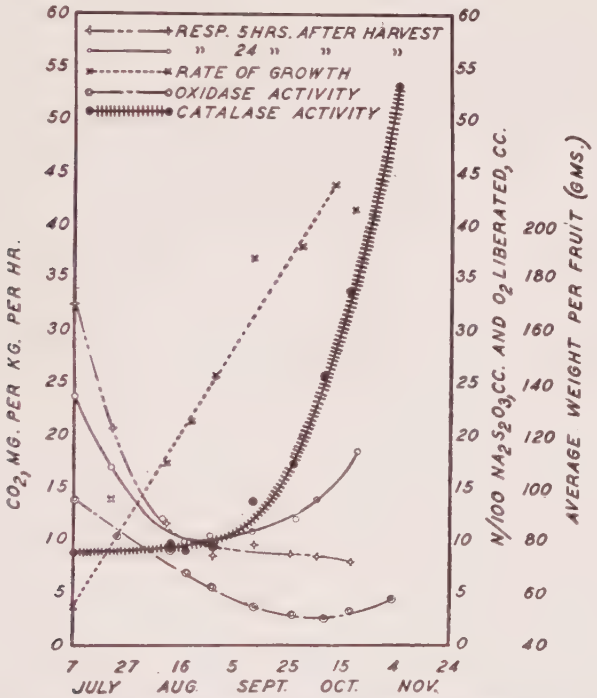

RESP. 5 HRS. AFTER HARVEST
" 24 " " "
RATE OF GROWTH
OXIDASE ACTIVITY
CATALASE ACTIVITY
CO_2, MG. PER KG. PER HR.
N/100 $Na_2S_2O_3$, CC. AND O_2 LIBERATED, CC.
AVERAGE WEIGHT PER FRUIT (GMS.)
0 5 10 15 20 25 30 35 40 45 50 55 60
40 60 80 100 120 140 160 180 200
7 27 16 5 25 15 4 24
JULY AUG. SEPT. OCT. NOV.

Fig. 34. Respiration rate, oxidase activity, catalase activity, and rate of growth of Delicious apples. Effect of the length of time interval (5 *vs.* 24 hours) between time of harvest and first respiration measurement is shown. Measurements made at 67°F. (20°C.).[260]

The question has arisen as to how accurately respiration measurements made in the laboratory reflect the true rate of respiration of fruit while still attached to the tree. For example, it has been shown in one study that the respiration rate of Washington apples was somewhat different when measured 5 hours after harvest than when measured 24 hours after. When the measurements were made 24 hours

[258] F. Kidd and C. West, *ibid., 1933,* 57 (1934).
[259] P. Harding, *Proc. Am. Soc. Hort. Sci., 26,* 319 (1929).

after harvest they found the usual strong climacteric rise in respiration rate. When the values were determined only 5 hours after harvest on successive picking dates, they did not find any marked rise[260] (see Fig. 34). Because these workers could find no sharply defined minimal rate prior to the respiratory rise and because they believed the usual measurements 24 hours after harvest did not reflect the true respiratory rate on the tree, they discounted the value of this technique as an index of when to pick apples. It should be noted in this connection that the respiration rate of apples has been measured *in situ* on the tree and has been found to be essentially that found 24 hours after harvest.[261] A similar finding has been made with tomato fruits.[262] It has also been found that apples do not reach full equilibrium with their atmosphere following harvest or removal from storage for 24 hours.[249]

Another significant value in knowing whether or not apples are pre- or postclimacteric is in connection with a possible relation to other physiological processes; for example, postclimacteric apples do not respond to ethylene additions.[256] Another example is the fact that the peak in production of organic volatiles seems to follow the respiratory peak in apples by several days at a high storage temperature.[244]

Variety of Apples. Since respiration rate is one of the best expressions of "rate of living" that we have, one would expect that the respiration rate of a given variety and its potential storage life could be easily correlated. Yet it is not always easy to compare varieties with regard to their respiration rate. For example, the respiratory activity of McIntosh on a given date at a given temperature might be 14 milligrams per kilo of fruit per hour and that of Baldwin 16. Yet McIntosh has a shorter storage life than Baldwin. This comparison is complicated by the fact that McIntosh was past the climacteric and Baldwin was at the climacteric when this comparison was made. Certainly all variety comparisons should be made in the same year, with apples from the same orchard, with fruits from identical cultural treatments, and at the same temperature. It is true that, in general, varieties with a short storage life have a more rapid respiration rate than varieties with a long storage life.

[260] B. D. Ezell and F. Gerhardt, *J. Agr. Research, 65,* 453 (1942).
[261] F. Kidd and C. West, *Rept. Food Inv. Board, 1937,* 114 (1938).
[262] K. A. Clendenning, *Can. J. Research, 20,* 197 (1942).

During 1945 an attempt was made to correlate respiration rates of varieties grown in the Cornell University orchards with their potential storage life. All comparisons were made at 74°F. (23°C.). A good correlation was found between the date of ripening of a given variety and the date on which it reached its climacteric. For example, the climacteric of McIntosh was reached in mid-September and that of Northern Spies in mid-October. This correlation held for ten varieties that were tested.

Another and better basis of comparison of varieties on the basis of respiratory activity is the height of the climacteric curve. There was a fair correlation when this comparison was made. For example, the peak value for Duchess of Oldenburg (a very short storage life variety) was 63 milligrams of carbon dioxide per kilo per hour, that of Wealthy (a short storage life variety) was 46, that of McIntosh (a moderately short storage life) was 34, and that of Rome Beauty (a long storage life) was 25. Yet all varieties did not fit this pattern perfectly. For example, Northern Spy which is a long storage life variety had a higher peak value (39) than McIntosh during 1945.

Another basis of evaluation of respiratory activity as an index of the known storage life of a given variety is the steepness of the respiratory rise to the climacteric. One would expect that those varieties which have a very steep rise to a peak might not keep as long in storage as those with a very gradual rise. A fair correlation was found here. For example, Wealthy and Duchess have a very steep climacteric rise, McIntosh has a moderately steep one, and Spy, Golden Delicious, Rome Beauty, Baldwin have a gradual rise.

Another basis of comparison of varieties is the steepness of the respiration curve after the climacteric has been passed. It will be recalled that following the climacteric there is a declining rate of respiration. One would expect that the faster the rate dropped to a very low point (or zero), the sooner it would reach the point of unmarketability; that is, the longer the apple respired more or less actively the longer one might expect the apple to remain marketable. There was a good correlation here with ten varieties with the possible exception of one variety.

Still another basis of comparison would be the cumulative respiration of different varieties. One would expect that possibly the more total carbon dioxide a variety was capable of giving off the longer its storage life might be expected to be. This would not nec-

essarily follow, however. One variety might give off more carbon dioxide than another during its life span and yet have a short storage life. Very little has been done in making comparisons between varieties on this basis. It has been found that McIntosh evolves from 17.5 to 19.5 grams of carbon dioxide per kilo of fruit during its marketable life (in a comparison of two years' fruit). Yellow Transparent (a rapidly ripening variety), McIntosh (a variety of moderate ripening rate), and Golden Delicious (a variety of slow ripening rate) all evolved similar amounts of total carbon dioxide. It would seem then that varieties with different potential storage life gave off about equal quantities of carbon dioxide during their life spans.

An attempt has been made to compare respiratory activity of different varieties with regard to the cell size of the parenchyma.[262a] In this survey it was found that varieties with small cell size in the parenchyma respired faster than those with large cells. Those with medium size cells were intermediate in rate between those with large and small cells. Of 16 varieties tested only Rome Beauty, Ontario, and Baldwin did not fit into this classification. It was also noted that those varieties with large cell size were those usually left longest on the tree before harvest.

Effect of Temperature. Most chemical reactions, according to van't Hoff's law, increase two or three times for every 18°F. (10°C.) rise in temperature. The exact increase for such a temperature rise has been called the temperature coefficient or Q_{10}. The Q_{10} for respiration of apples varies with variety, temperature of the storage, composition of the atmosphere, and age of the fruit. In general, of course, the respiration rate of apples rises with an increase in temperature. In studies of different varieties the Q_{10} for apple respiration has been shown to vary between 2.1 and 2.9.[263,264] Cornell studies show a range of 2.0 to 3.0. A Q_{10} as high as 3.27 has been found for English-grown apples in the temperature range studied.[254]

Generally speaking then the respiration rate of a given variety of apples might be twice as much at 50°F. (10°C.) as it is at 32°F. (0°C.). This effect of lowering of the temperature constitutes one of the main principles of cold storage. It should be noted that some of the factors above which modify the Q_{10} may be very striking. For

[262a] W. H. Smith, *Rept. Food Inv. Board, 1936,* 137 (1937).
[263] H. C. Gore, *U. S. D. A. Bur. Circ.* 142, 1911.
[264] F. W. Morse, *New Hampshire Agr. Expt. Sta. Bull.,* 135, 1908.

example, a given lot of McIntosh apples at 50°F. (10°C.) at its respiratory peak may respire faster than a second lot of McIntosh at 60°F. (16°C.) which is preclimacteric. See Table 19, page 158.

With some plant products there is an increase in respiration after the products have been subjected to cold storage temperatures and then removed to high temperatures. Although this temporary effect of low temperatures has been noted in at least one study with rather immature apples[265] the subsequent respiration of apples in general does not seem to be affected by low temperature storage.[266–268]

It is sometimes stated that cold storage apples "go to pieces" rapidly after being taken to room temperature. This effect would certainly not seem to be due to an increased respiration rate due to prior storage at low temperatures. The reason apples "go to pieces" rapidly in such a situation is merely due to the fact that the fruits are "old" when removed from storage and removal to high temperatures near the end of the storage season makes the "old age" all too evident.

Effect of Delayed Storage. One would naturally expect that holding apples at a relatively high temperature (such as 60–70°F.) for a few days or a week prior to low-temperature storage would shorten the storage life of apples.[269] This is true because during the high-temperature holding period the apples are respiring very fast and lose considerable of their potential storage life. Respiration measurements of Washington Delicious apples that were held four days at 65°F. before cold storage at 31°F. have shown that there was little actual difference in respiration rate between this fruit and apples stored immediately when both were held at 31°F.[270] Fruit subjected to a delay at high temperatures at harvest time but held thereafter at 31°F. (—0.6°) respired at a lower rate than when stored immediately at 36°F. (2°C.) and held continuously at that temperature.

Effect of Carbon Dioxide. The presence of carbon dioxide

[265] A. M. Burroughs, *Rept. Marble Lab., Inc., 3,* 101 (1923).
[266] C. A. Eaves, *Sci. Agr., 16,* 28 (1935).
[267] P. Harding, *Iowa Agr. Expt. Sta. Research Bull.,* 182, 1935.
[268] R. M. Smock, *Botan. Gaz., 104,* 178 (1942).
[269] J. R. Magness, H. C. Diehl, M. H. Haller, W. S. Graham, D. B. Carrick, F. S. Howlett, R. E. Marshall, H. H. Plagge, and G. H. Raleigh, *U. S. D. A. Bull.,* 1406, 1926.
[270] F. Gerhardt and E. Smith, *Proc. Wash State Hort. Assoc., 41st Ann. Meeting, 1945,* 1 (1946).

around apple fruits tends to slow down the respiration rate. In general, the higher the concentration of carbon dioxide the more the respiration rate is depressed.[271–274]

The effect of carbon dioxide might be explained on the basis of the law of mass action, *i.e.*, with accumulations of carbon dioxide around the fruit the rate of respiration would be slowed down because one of the end products was not being removed. The real reason why carbon dioxide slows down the respiration rate of apples is probably not yet known. However, it has been suggested that in some plant tissues there is an effect of carbon dioxide on *p*H of the tissues and hence on respiration.[275] This raises the question whether the change in *p*H just accompanies the retarded respiration or causes it. This effect of carbon dioxide on respiration is made use of commercially both in carbon dioxide treatments and controlled atmosphere storage. In the latter, the carbon dioxide evolved by the fruit in respiration is utilized as the source of carbon dioxide to retard ripening rate.

There is a limit to how much carbon dioxide may be used in trying to retard the respiration rate; apples are sensitive to excess quantities of this gas. Cornell studies have shown that Baldwin and Rhode Island Greening apples cannot tolerate more than 1 or 2% of carbon dioxide at 40°F. McIntosh can tolerate as much as 8–10% at 40°F. (4°C.) but at 32°F. (0°C.) cannot tolerate more than 1 or 2%. This indicates that there is a variety difference in toleration of this gas and that in general apples are more tolerant of its presence at high temperatures than at low. Carbon dioxide toxicity has also been noted in English and Australian apples.[276,277] Carbon dioxide injury is evidenced by browning of the flesh in some varieties and (or) by rough depressed areas on the skin of other varieties. In some varieties (like Baldwin, Wealthy, and Jonathan) there is not only a browning of the flesh but also a corky appearance in the affected portion. Large areas of flesh break away from each other leaving gaps between the dry, corky appearing tissues.

[271] F. Kidd and C. West, *Rept. Food Inv. Board, 1925,* 41 (1927).
[272] F. Kidd and C. West, *ibid., 1933,* 51 (1934).
[273] F. Kidd and C. West, *ibid., 1937,* 101 (1938).
[274] A. Van Doren, *Proc. Am. Soc. Hort. Sci., 37,* 453 (1939).
[275] N. C. Thornton, *Contribs. Boyce Thompson Inst., 5,* 403 (1933).
[276] J. Barker and F. Kidd, *Rept. Food Inv. Board, 1934,* 109 (1935).
[277] W. M. Carne and D. Martin, *J. Council Sci. Ind. Research, 11,* 47 (1938).

Susceptibility to a given concentration of carbon dioxide may also depend upon growing or climatic conditions in the orchard. Iowa grown Jonathan apples seem to be able to tolerate 5% of carbon dioxide at 40°F. (4°C.) but New York grown Jonathan develops a type of flesh browning described above with that amount of carbon dioxide.[278,279] Variations in susceptibility within a given variety seem also to vary from year to year.

Effect of Oxygen. When the amount of oxygen present in the atmosphere is reduced, there is a reduction in the rate of apple respiration. This is easily explained by the fact that oxygen is one of the reacting materials in the process of respiration. When it is limiting in amount either in the external atmosphere or internal atmosphere of the fruit, the respiration rate is reduced.

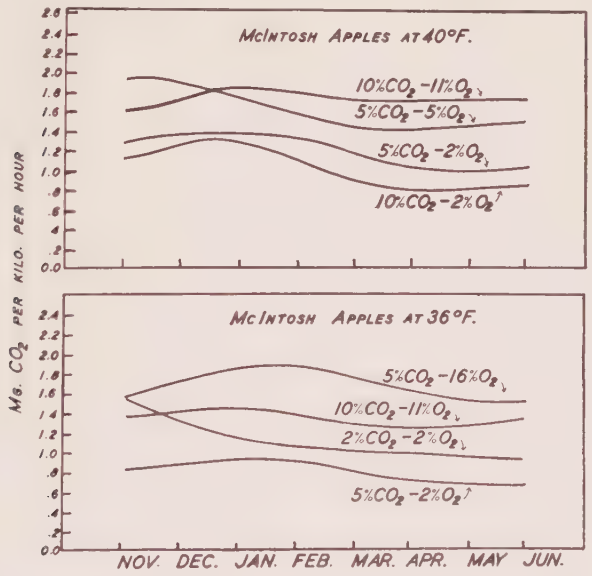


Fig. 35. Respiration rate of McIntosh apples in various carbon dioxide-oxygen mixtures at two storage temperatures.[274]

[278] H. H. Plagge, *Refrig. Eng., 43,* 215 (1942).
[279] R. M. Smock and A. Van Doren, *Cornell Univ. Agr. Expt. Sta. Bull.,* 762, 1941.

It would seem safe to say that reductions in oxygen concentration have a more marked effect on apple respiration than carbon dioxide accumulations.[274] Part of this may be due to the fact that oxygen can be lowered from a normal of 21% to 2% without injury whereas carbon dioxide can be raised only to about 5% (from 0.25% to 5%) over a long storage period. In other words, the difference between the effects of the two gases is not only qualitative but quantitative in controlled atmosphere storage.

In one study with oxygen–nitrogen atmospheres it was reported that the respiration rate of apples actually decreased with increasing oxygen concentrations up to 5 to 9% and then increased as concentrations up to 100% were used.[280] However, in actual tests with oxygen at different levels in combination with carbon dioxide at cold storage temperatures the lowest respiration rate came with the lowest oxygen concentration.[274] This latter finding would seem to have more practical bearing on the problem of storage of apples in controlled atmosphere storage (Fig. 35).

Use of the knowledge of this inhibiting effect of low oxygen concentration is made in controlled atmosphere storage. In this type of storage the oxygen is lowered by means of fruit respiration itself. There is also a reduction in oxygen supply (and also a carbon dioxide accumulation)[281] when fruits are waxed.[282] Attempts to slow down the respiration rate too much by means of waxing are sometimes dangerous. If the artificial wax coating is too thick oxygen may become limiting or toxic concentrations of carbon dioxide may accumulate.[282,283]

Of course, the oxygen level of fruits must not be allowed to drop too low or anaerobic respiration results. As a matter of fact, we do not know just how much anaerobic respiration may take place in apples when the external atmosphere is 3% oxygen (and the internal atmosphere within the fruit may be somewhat lower). Of course, there may even be temporary or prolonged anaerobic respiration in apples at higher oxygen levels when the temperature is high or if for some other reason respiration is very rapid. We do know that if the oxygen level drops below 2% for more than a few days at a

[280] F. F. Blackman, *Proc. Roy. Soc. London, 103,* 491 (1928).
[281] F. Kidd and C. West, *Rept. Food Inv. Board, 1934,* 110 (1935).
[282] R. M. Smock, *Proc. Am. Soc. Hort. Sci., 33,* 284 (1936).
[283] S. A. Trout, E. G. Hall, R. N. Robertson, Frances M. V. Hackney, and S. M. Sykes, *Australian J. Exptl. Biol. Med. Sci., 20,* 219 (1942).

time with McIntosh apples that anaerobic respiration is likely to follow and off flavors will ensue. Even at low storage temperatures there is often a lag of 2–5% in oxygen concentration in the fruits' internal atmosphere.[281]

Whether or not the respiration rate of apples may be increased seems to depend upon the age of the fruit. If oxygen supply is actually limiting (due to rapid respiration or increased resistance of the skin to diffusion) the respiration rate may be increased by additions of oxygen to the atmosphere.[252] Of course, from a commercial standpoint we are not particularly interested in speeding up the respiration rate. Even if we were, with apples it could probably be best done by some other means.

Residual Effect of Carbon Dioxide on Respiration. It has already been pointed out that accumulations of carbon dioxide and reductions in oxygen concentration slow down the respiration rate of apples. It has also been found that there is a residual effect of this treatment, that is, following removal from controlled atmosphere storage there is a slower than normal rate of respiration.[268] It is as though the apples had been partially anesthetized during storage and never quite recovered. Figure 36 illustrates the fact that following

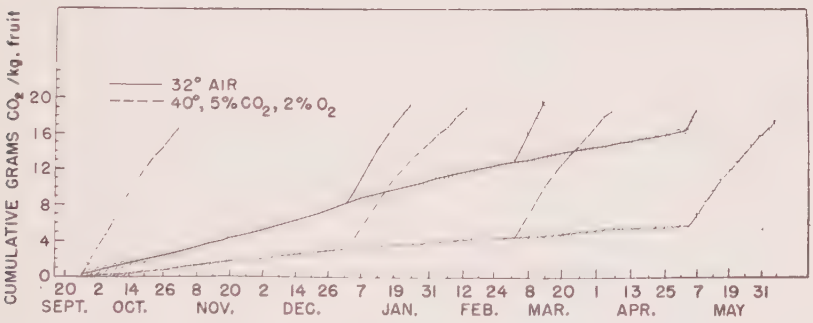

CUMULATIVE GRAMS CO_2 /kg. fruit
0
4
8
12
16
20
32° AIR
40°, 5% CO_2, 2% O_2
20 2 14 26 8 20 2 14 26 7 19 31 12 24 8 20 1 13 25 7 19 31
SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY

Fig. 36. Cumulative respiration of McIntosh apples in 32°F. (0°C.) air and controlled atmosphere storage at 40°F. (4°C.) (represented by the two most nearly horizontal lines). Cumulative respiration at harvest time, and upon removal from storage in January, March, and May at 74°F. (23°C.) (represented by the seven most nearly vertical lines).[268]

removal from controlled atmosphere storage in March and May, McIntosh apples respired even more slowly than one would have anticipated.

Effect of Stimulating Chemicals. *Ethylene* has been used for many years to ripen certain fruits, *e.g.*, bananas and oranges.[284] Its use to stimulate the respiration rate of apples has not become widespread because the problem is usually one of delaying respiration

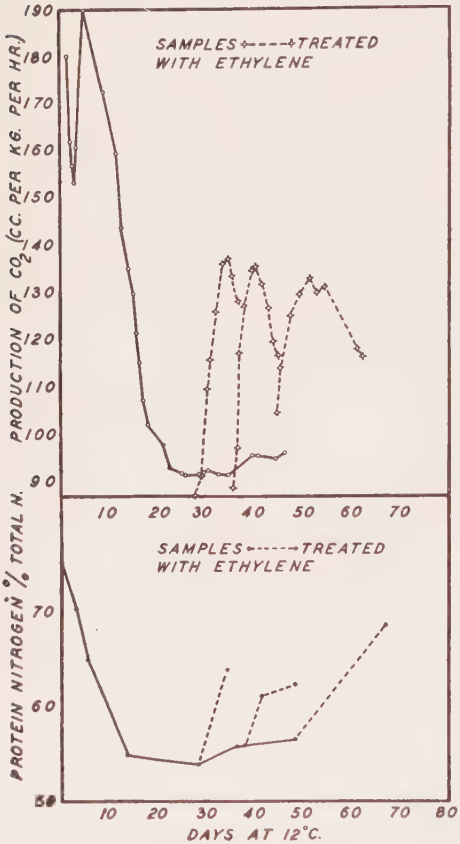


Fig. 37. Changes in the rate of respiration (upper graph) and protein nitrogen (lower graph) in Bramley's Seedling apples as affected by ethylene additions to the atmosphere at 53.6°F. (12°C.).[284a]

rather than hastening it. However, ethylene has been used in some special cases with apples. For example, one processor likes to start his canning operations as early in the fall as possible, yet the apples are entirely too acid and astringent for canning purposes. He used ethylene to ripen the apples for a period of several weeks.

Ethylene usage definitely stimulates the respiration of pre-

[284] E. M. Harvey, *Minn. Hort.*, *54*, 140 (1926).
[284a] F. Kidd, C. West, and A. C. Hulme, *Rept. Food Inv. Board*, *1938*, 119 (1939).

climacteric apples.[219,220,285] It should be noted here that ethylene has no effect on postclimacteric apples. Why this is true is not known. It might be due to the fact that the apples themselves begin to give off ethylene in appreciable quantities when they reach the climacteric and any artificial additions can have no effect after that time (Fig. 37).

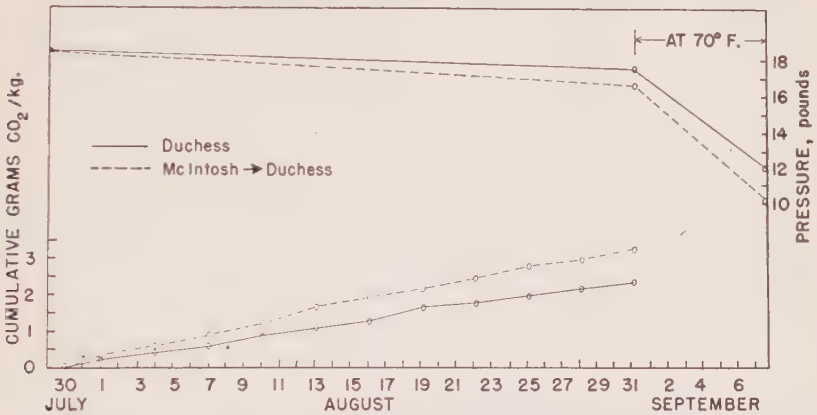


Fig. 38. Effects of the emanations of ripe McIntosh apples on the cumulative respiration (lower) and the firmness (upper) of preclimacteric Duchess apples at 33°F. (0.6°C.). Losses in firmness held after storage at 70°F. (21°C.) shown also. Downward pointing arrow indicates date when ripe apple treatment was started. Upward pointing arrow indicates date of cessation of ripe apple treatment.[256]

The practical implications of the effect of ethylene on apple respiration are even greater when one remembers that apples themselves give off ethylene as they ripen. This subject is discussed in detail in a previous section. Kidd and West[219] were probably the first workers to recognize the possibility of one lot of apples stimulating the respiration of a second lot of fruit. The magnitude of the effect on respiration resulting from exposure of apples to ripe apples has been found to depend upon a number of factors: (*a*) the *age* of the fruit—only preclimacteric fruits are affected by ripe fruit emanations containing ethylene[256]; (*b*) some apple varieties show more marked respiratory response than others[256]; (*c*) the temperature of the storage (significant effects were observed at temperatures as low as 33°F. (0.6°C.) but more striking effects were observed at

[285] F. Kidd and C. West, *Rept. Food Inv. Board, 1937*, 108 (1938).

higher temperatures[256]); (*d*) the number of ripe fruits—it required as few as 1% of the total fruits in the storage chamber to stimulate a respiratory rise; (*e*) the variety of the ripe fruit (some varieties seem to evolve more ethylene than others); and (*f*) ripeness of the apples supplying the ethylene. In view of the foregoing conditions it may be seen that one lot of apples may have no effect on the respiration of another lot or it may have a very significant effect. Figure 38 illustrates the cumulative effect of ripe McIntosh vapors on Duchess apples at 33°F. (0.6°C.). The possibility of air purification to remove naturally evolved ethylene in storage is discussed in another section.

Artificial additions of *acetylene* have shown a stimulation in the respiration of some fruits and there is little reason to think it would not have the same effect on apples.[286,287] Acetylene seems to have an effect very similar to that of ethylene. Danger of explosion of this gas when used for ripening purposes would seem to be good reason for not using it.

The use of *2,4-dichlorophenoxyacetic acid* ("2-4-D") stimulates the ripening rate of preclimacteric apples.[288] This material has been used for ripening purposes as a spray, a dip, or as an aerosol treatment. In the original study with this material with apples, respiration measurements were not made, but Cornell studies have shown that it does stimulate the respiration of preclimacteric apples.

When *naphthaleneacetic acid* is used as a "stop-drop" spray there is a strong possibility that it may result in accelerated respiration. Of course, one might expect that hormone-sprayed apples might be respiring faster upon harvest because they might be high on the climacteric rise when harvested. On the other hand, there seems to be a *direct* stimulatory effect of this material under some circumstances.[289] In the original study made on this point no effect of the spray could be noted on the respiration of apples at cold storage temperatures when they were harvested within 10 days or 2 weeks after the application of a 0.001% spray with this material. A marked direct effect was noted after that time, however. In Cornell studies at

[256] R. Davies and W. W. Boyes, *Rept. S. Africa Dept. Agr. Low Temp. Research Sta., 1938–39,* 31 (1940).
[287] J. E. van der Plank and G. F. van Wyk, *ibid., 1938–39,* 9 (1940).
[288] J. W. Mitchell and P. C. Marth, *Botan. Gaz., 106,* 199 (1944).
[289] F. Gerhardt and D. F. Allmendinger, *Proc. Am. Soc. Hort. Sci., 46,* 118 (1945).

high temperatures the direct effect of the spray has been noted within 3 days after applying the material.[289a] While this effect is certainly not a desirable one, it is not serious enough to argue against

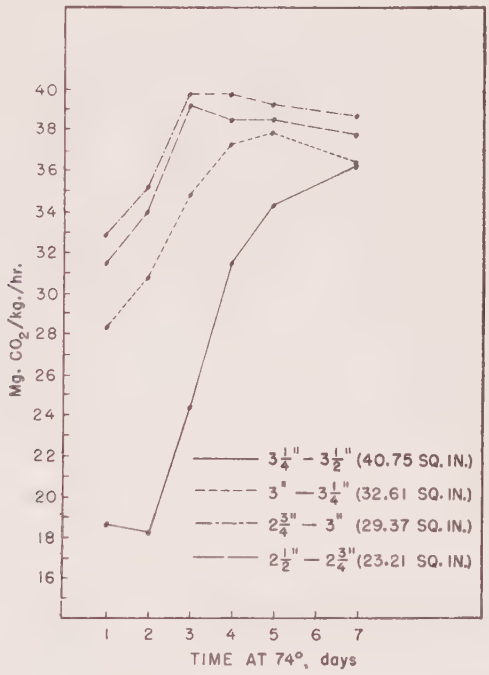


Fig. 39. Effect of size and surface area of fruits on the respiration rate of Wealthy apples at 74°F. (23°C.).

the use of such sprays. These studies do emphasize, however, the fact that hormone-sprayed apples should certainly not be allowed to hang on the trees too long. They also indicate that fruit sprayed with such materials should be stored promptly at a low temperature and not held too long in storage.

Effect of Fruit Size. It is quite often stated that small fruits keep longer and better in storage than do large ones. It should be recognized here that factors other than respiration rate may be involved. For example, small apples are usually firmer when placed

[289a] R. M. Smock and C. R. Gross, *ibid., 49,* 67 (1947).

in storage than large ones. They are also usually less subject to storage disorders like bitter pit and scald.

The senior author (R. M. Smock) has conducted a number of experiments on the effect of fruit size on respiration of apples. One would expect a given weight of small apples to respire faster because of the surface area factor. In general, it seemed that small fruits respired faster than large ones. This was especially apparent when the fruits were taken from fruit thinning experiments, that is, fruits grown with a large leaf–fruit ratio (*i.e.,* many leaves per fruit) respired slower than those with a small ratio (see Fig. 39). This effect of fruit size on respiration rate was not a clear-cut one, however. In some experiments in which apples were harvested at random from a tree and then segregated as to size, it was found that large apples might respire faster than small ones.

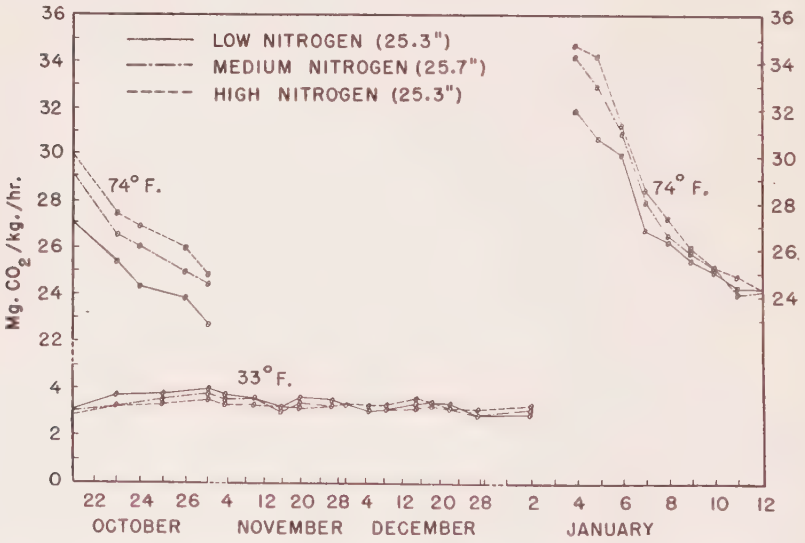


Fig. 40. Effect of differential nitrogen treatments in the orchard on the respiration rate of McIntosh apples at 33°F. and 74°F. Measurements made at 74°F. (23°C.) in January were following removal of the apples from storage at 33°F. (0.6°C.). Fruit surface areas are given in parentheses.

Effect of Culture and Climate. The exact effect of nitrogen fertilization on the respiration rate of apples is not entirely clear. One study indicated no stimulation in respiration as a result of

fertilization of the trees with nitrogen.[290] This lack of response was apparent in this study even though the nitrogen content of the fruits was increased by the fertilizer application in the orchard. Other studies have shown increases in respiration rate as a result of nitrogen fertilization.[291]

Injections of urea into a tree and spraying the leaves of the tree with urea have resulted in increases in the respiration rate of apples.[292] The senior author (R. M. Smock) has found a rather marked increase in respiration of McIntosh apples as a result of nitrogen fertilization when stored at high temperatures but no measurable effect at low temperatures. The effect of nitrogen (at a high temperature) was not due to the fact that larger fruit were used in the nitrogen treatments since all fruits were chosen of the same size (see Fig. 40).

A review of the problem of *mineral deficiency* as it might affect respiration rate of apples would indicate that there are no clear-cut relationships between this factor and respiration rate.[293] However, in one study in which it was not clear whether a real potassium deficiency actually existed, it was found that an application of *potassium* had no effect on subsequent respiration of apples in storage.[294]

The exact effect of *climate* during the growing season on the respiration rate of apples in storage has not yet been fully explored. Unpublished work by the senior author indicates marked fluctuations in the rate of respiration of McIntosh apples picked from the same trees from year to year. One worker has claimed that low respiration rate in storage was correlated with warm dry weather during the few weeks preceding harvest.[295] It has been noted that high respiration rate following harvest seemed to be associated with relatively warm summers at Ithaca, New York. This observation needs to be checked for many years before any real conclusion can be drawn on this point. Many factors vary from year to year in the orchard as well as temperature.

[290] J. H. Gourley and E. F. Hopkins, *Ohio Agr. Expt. Sta. Bull.*, 479, 1931.
[291] F. Kidd and C. West, *Rept. Food Inv. Board, 1936*, 133 (1937).
[292] A. C. Hulme, *Ann. Rept. East Malling Research Sta. Kent, 1936*, 185.
[293] T. W. Wallace, *Proc. First Imp. Hort. Conf.*, Pt. III, 9 (1931).
[294] E. S. Degman and J. H. Weinberger, *Maryland Agr. Expt. Sta. Bull.*, 366, 1934.
[295] C. West, *Rept. Food Inv. Board, 1929*, 52 (1930).

Effect of Ringing. Ringing of tree limbs in early summer has been found to increase the respiration rate of apples at harvest time.[296]

Effect of Injury. Many plant tissues respire faster when wounded. Most studies with apples have shown little or no effect of bruising on respiration rate but skin punctures or cutting the fruit does seem to stimulate respiratory activity.[297,298] The effect of

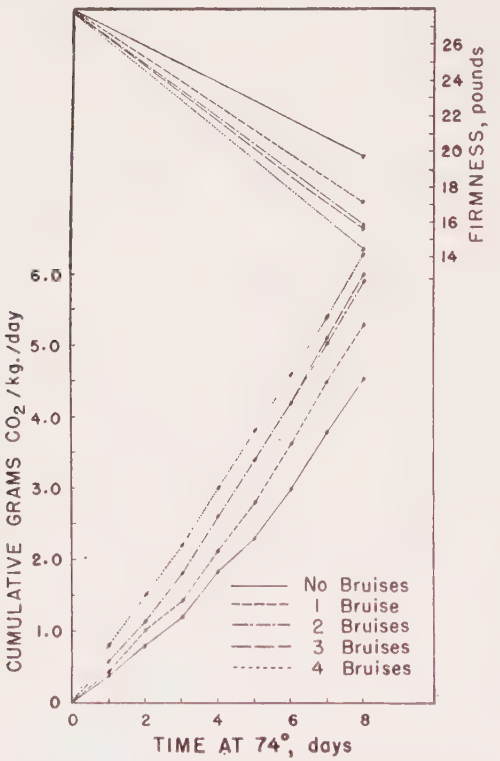


Fig. 41. Effect of bruising (different numbers of bruises per fruit) on the cumulative respiration and firmness losses of Winter Banana apples at 74°F. (23°C.).

bruising on several varieties of apples of different ages has been made at Cornell. Very frequently there is no effect of two bruises per fruit on a number of varieties, but there has been found to be a stimulatory effect on other varieties (see Fig. 41).

[296] M. Onslow, F. Kidd, and C. West, *ibid., 1932,* 70 (1933).
[297] B. D. Drain, *Botan. Gaz., 82,* 183 (1926).
[298] F. Kidd, *Rept. S. Africa Dept. Agr. Low Temp. Research Sta., 1931,* 111 (1932).

Severe injury to the cells of fruits, as may be caused by *freezing* followed by thawing, is likely to induce a subsequent rise in respiration rate.[299]

Winesap apples frozen for from 3 to 6 hours at temperatures of 16.9°F. to 18.5°F. increased their respiration at 32°F. as much as 85% above their previously normal performance at that temperature. This acceleration lasted for several days, gradually declining so that slight effects were to be noted one month after the treatment. When the fruit was frozen enough to kill about 80% of the cells, the evolution of carbon dioxide at 32°F. was only one third that which was normally produced at that temperature.

Effect of relative humidity. One might assume that high relative humidities in the atmosphere might slow down the respiration rate of apples by the law of mass action. Water vapor, *i.e.*, metabolic water, is one of the end products of the process.

Actual studies have shown that the relative humidity did not affect the respiration of apples unless the humidity became very low.[300] This reduction could be attributed to physical changes in the character of the skin of the fruit which accompanied shrivelling. In other words, the resistance to diffusion of gases was increased. Variations in relative humidities in the higher ranges (70–100%) seemed to be ineffectual in affecting respiration rate. A plausible explanation of this lack of effect might be the fact that the humidity of the intercellular spaces of the fruit stays close to saturation until the apples become somewhat desiccated. In other words, external changes in relative humidity may not markedly affect internal relative humidity until considerable quantities of water have been lost from the fruit.

2. HEAT OF RESPIRATION

It has already been pointed out that energy is evolved during respiration. Assuming that a hexose sugar is completely oxidized during respiration the heat produced would be 673 calories per kilogram of hexose sugar consumed. Actual investigation has shown that the heat produced by apples was within 10% of this figure.[301]

[299] D. B. Carrick, *Cornell Univ. Agr. Expt. Sta. Mem.*, 110, 1928.

[300] S. A. Pieniazek, *A Study of Factors Influencing the Rate of Transpiration of Apple Fruits. Thesis, Cornell Univ.*, 1942.

[301] W. P. Green, W. V. Hukill, and D. H. Rose, *U. S. D. A. Tech. Bull.*, 771, 1941.

This would indicate that most or all of the energy evolved during respiration of apples was in the form of heat energy (see Table 20).

TABLE 19 (*see page 144*). RESPIRATION IN RELATION TO TEMPERATURE[269]

Apple variety and station	Temperature °F.	Temperature °C.	CO_2 per kg. per hr., mg.
Grimes Golden, Rosslyn, Va.	32	0	4.76
	40	4	8.34
	60	16	29.25
	85	30	67.82
Jonathan, Yakima, Wash.	32	0	3.45
	40	4	7.20
	60	16	26.48
Baldwin, Rosslyn, Va.	32	0	2.90
	40	4	5.37
	60	16	19.65
	85	30	38.49
Winesap, Linden, Va.	32	0	2.75
	40	4	5.30
	60	16	20.45
	85	30	33.95

TABLE 20. HEAT GENERATED BY APPLES DURING RESPIRATION MEASURED BY HEAT CALORIMETER AND CALCULATED FROM CARBON DIOXIDE PRODUCTION[301]

Variety	Temperature °F.	Temperature °C.	Measured heat of respiration per ton per day, B.T.U.	Heat calculated from CO_2 production per ton per day, B.T.U.
"Apples"	65	18	7900	8770
York Imperial	45	7	1490	1465
Stayman Winesap	45	7	1551	1632

Studies on heat of respiration should not overlook the fact that heat evolved may vary with age of the fruit as well as the variety. Not even the variety is specified in many studies carried on in connection with heat of respiration. It should be recognized that the Q_{10} is not a constant for even a given variety and hence one cannot accurately compute heat values from a single reading at one temperature.

A knowledge of the magnitude of heat of respiration is of utmost value to the refrigeration engineer who must compute refrigeration requirement. The authors have taken the figures of

Griffiths and Awberry[302] and calculated the rise in temperature of apples in storage. Assuming that there is no heat loss (as there inevitably would be) a bushel of "apples" at 32°F. (0°C.) would raise their own temperature 2°F. in 23 hours. Calculations of this type are open to criticism for obvious reasons but they do illustrate something of the magnitude of the heat of respiration of apples.

Relation of Respiration Rate to Length of Storage Life. In many studies there has been good correlation between respiration rate of apples and storage life, that is, when respiration rate was low the storage life was long. Some workers have gone so far as to forecast the potential storage life of an apple from a knowledge of the height of the climacteric rise, date of the rise, and the general level of respiration.[290] All too frequently factors other than respiration rate may determine the storage life of apples. Physiological disorders or fungus troubles of the apples in storage may well determine the length of storage life. It is true, however, that respiration rate is one of the few measurements we have of "rate of living" that is even reasonably reliable.

Sometimes cumulative respiration curves are of value in determining the "age" or potential storage life of apples. These cumulative curves are constructed by plotting the total amounts of carbon dioxide evolved for each 24-hour period. One might even extrapolate a cumulative respiration curve to determine approximately how long it would be before a given lot of apples will reach a certain total amount of carbon dioxide evolved. One difficulty with such a technique is that physiological disorders may be limiting factors in determining length of storage life. It has been found that the marketable life of McIntosh apples as grown in New York was at an end when this variety had evolved between 17.5 and 19.5 grams of carbon dioxide per kilogram of fruit when harvested each year at about the same point on the respiratory curve. This represents an error of at least 10% when complicating factors like brown core are excluded (see Fig. 36). Such cumulative curves would doubtless indicate marked differences between varieties with regard to their potential storage life. It should be remembered, however, that respiration rate might not vary much between varieties and yet they might have differences in potential storage life.

[302] E. Griffiths and J. H. Awberry, *Rept. Food Inv. Board*, 1927, 88 (1928).

CHAPTER VII

FRUIT MATURITY AND QUALITY

A. Determination of Fruit Maturity

It is exceedingly important that apples be harvested at the right time. The exact degree of maturity at which a given variety should be picked depends in large part on what disposition is to be made of the fruit. If the apples are to be sold for the fresh fruit market very shortly after harvest they might be allowed to become almost eating ripe on the tree. If they are to be held in storage for a rather extended period they must be picked some little time before they are eating ripe. If they are to be used for cooking purposes (either immediately after harvest or after cold or freezing storage), they must be picked while they still have proper cooking quality.

If apples are picked too soon and then stored for any length of time they are very subject to storage troubles such as bitter pit and scald. They are likely to be of low dessert quality because they do not have the proper complement of sugars and other quality contributing factors. On the other hand, if apples are picked too late they are likely to have a short storage life and will break down prematurely. Apples picked too late are also subject to storage troubles like Jonathan spot and Spy spot. Excessive dropping or abscission from the tree may take place if the apples are allowed to remain on the tree too long.

It is difficult to give explicit directions as to the best time to pick the various apple varieties. No one index of maturity is infallible, and often the use of a combination of indices is disappointing in its results. The physical and chemical changes in the apple just prior to and during harvest proceed so slowly that it is almost impossible to select any of these changes as an infallible index of the rate of ripening. Almost every measure or index of maturity has to be defined for not only a given variety but for a given location, season, and soil type. Some of the more important and useful measures of maturity are discussed in the following paragraphs.

Ground Color Changes. Ground color refers to the underlying green or yellow color on even the red varieties. As apples ripen on the tree the dark green undercolor changes to a slight tint of yellowish green and later to full yellow. The United States Department of Agriculture[303] has prepared a color chart to assist in describing the ground color as to its shade of green or yellow. The exact shade of green or yellow to be sought in deciding when to pick depends upon the variety and in some cases the season. McIntosh and Baldwin may drop to the ground before their ground color changes much. Cortland, on the other hand, has almost a full yellow ground color when it is harvested for best keeping and freedom from scald. In seasons when ripening is unusually early, the ground color test seems to be less useful than during normal seasons.

Experience is required to determine accurately at just what shade of ground color the various varieties should be harvested, but this test, despite its limitations, is one of the most useful measures of maturity. With McIntosh it is probably the best test.

Ease of Separation. The ease with which the fruit separates from the tree is also a useful index of maturity.[303] As the apple matures on the tree it separates more and more readily from the spur. If allowed to hang long enough, it drops off the tree. Varieties of apples hang on the tree with varying degrees of tenaciousness. McIntosh tends to fall before it is fully ready to harvest; Cortland may hang on the tree for quite some time after the proper time of picking. Seasonal conditions and culture affect the tenacity with which some sorts hang on the tree; for example, excessive use of nitrogen may make McIntosh fall prematurely. Although apples should be picked before serious dropping occurs, they should certainly not be picked when the spurs come off with the fruit or the fruit stems pull out in harvesting. In spite of the limitations of this index of maturity, it can be helpful after one gains a little experience with the different varieties.

With the advent of "hormone" sprays to prevent the dropping of fruits in such varieties as McIntosh, the value of this test of maturity is lessened. Once the apples have been sprayed, they may need to be picked before they separate easily from the spur.

Firmness of Fruit on Tree. As the apple matures on the tree it becomes softer. While an experienced fruit grower may be able to

[303] J. R. Magness, H. C. Diehl, and M. H. Haller, *U. S. D. A. Bull., 1448*, 1926.

tell differences in fruit firmness by feeling the fruit, one cannot make very accurate determinations of firmness by this method. A very exact measure of firmness may be made by using one of several types of mechanical pressure testers.[304,305] One common type indicates in pounds the pressure required to force a plunger seven sixteenths of an inch in diameter into the apple to a depth of five sixteenths of an inch (see Fig. 42).

Fig. 42. Refractometer for measuring total soluble solids in apple juice (top). Pressure tester for measuring fruit firmness (bottom).

A thin slice is removed from the surface of the fruit before making the pressure test with the Magness-Taylor tester. The fruit may be placed against a solid surface before making the test. The plunger tip is placed against the cut surface and pressure is applied. When the plunger tip has penetrated to a depth of five sixteenths of an inch, as shown by a line on the plunger tip, the pressure reading may be taken from the scale directly. In order to obtain a satisfactory indication of the condition of any variety, at least 10 to 20 apples selected from different trees and different parts of the trees should be used. Two tests can be made to an apple but it is thought preferable to take one test on an unblushed portion of the fruit, about midway between stem and calyx end if possible.

The value of the pressure tester is not limited by its accuracy but by other factors. In fact, limitations of the test are so numerous that it raises the question of just what real value the test may have. Certainly, one should keep in mind all the limitations of the test before trying to evaluate any pressure test data. One Eastern experiment station[306] has recommended a pressure test of 15 pounds for the

[304] J. R. Magness and G. F. Taylor, *U. S. D. A. Circ., 350,* 1925.
[305] C. Hesse and A. L. Schrader, *Proc. Am. Soc. Hort. Sci., 33,* 210 (1936).
[306] C. I. Gunness, W. R. Cole, and O. C. Roberts, *Mass. Agr. Expt. Sta. Bull., 360,* 1939.

harvest of McIntosh. It is doubtful if one can make such a recommendation unless he has taken into consideration the following limitations.

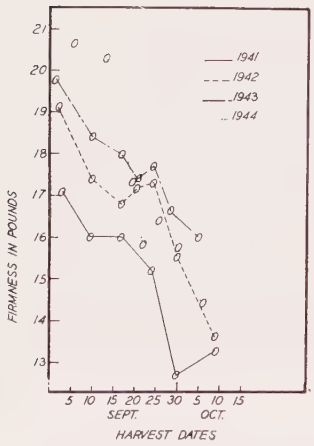


Fig. 43. Changes in firmness of McIntosh apples as influenced by time of harvest over a period of four years in the same orchard.

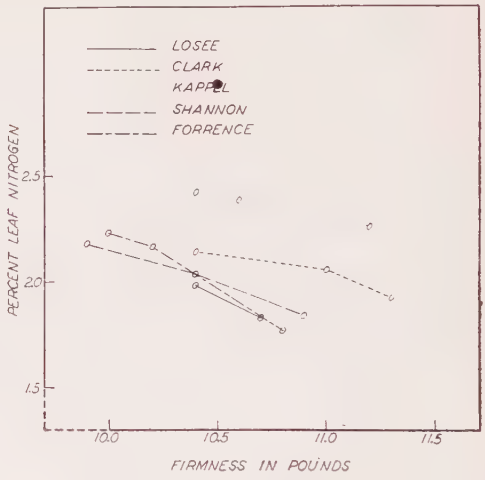


Fig. 44. Relation of firmness of McIntosh apples and leaf nitrogen content in five New York orchards. Fruit firmness measured after storage at 32°F. (0°C.) and leaf nitrogen in July of the previous summer.[307a]

(*a*) The firmness of a given variety varies from season to season. It has been found that McIntosh apples were picked in optimum condition one year at 14 pounds but in another year at 16 pounds.

(*b*) The firmness of a given variety varies from section to section. This is doubtless due to climatic conditions that also affect seasonal variations. Soil factors may also be involved.

(c) The pressure tester usually gives a higher reading on the blushed side of the fruit than on the unblushed side but this difficulty can be overcome by always testing on an unblushed portion of the fruit.

(*d*) Mature, well-colored apples on the outside of the tree may have a higher pressure test than less mature apples on the inside of the tree.

(*e*) Soil fertilization with nitrogen treatment may affect the firmness of the McIntosh apple (see Fig. 44).

(*f*) Temperature of the fruit[307] and its moisture content[308] have an effect on the pressure test reading.

[307] M. H. Haller, *U. S. D. A. Circ., 627*, 1941.
[307a] R. M. Smock and D. Boynton, *Proc. Am. Soc. Hort. Sci., 45*, 77 (1944).
[308] M. H. Haller, *ibid., 35*, 205 (1937).

(*g*) Fruit size has an influence on firmness. Large fruits are usually but not always softer than small fruits.[307]

It would hardly seem safe to use this test as a reliable means of telling when to pick a given variety. The primary usefulness of the test is to tell the difference in firmness between two or more lots of the same variety on a given date or to tell the *general* degree of ripeness.

Soluble Solids Content. The percentage of soluble solids present in apples has been used as an index of when to pick apples in some instances. A portable refractometer (see Fig. 42) gives a reading of soluble solids directly as a percentage. A few drops of juice can be caught as the pressure tests are made on each apple in a small container. The composite sample from many apples is then well mixed and a few drops placed on the refractometer.

The justification for this test is that the main constituents of the soluble solids are the sugars and it is known that the sugar content of the juice increases steadily as the fruit matures on the tree. Table 21 illustrates the changes that take place in McIntosh apples as the picking season progresses.

The value of this test is limited not by the accuracy of the measurement but by the fact that the increases in sugars are small from week to week, that is, the amount of solids may vary more from tree to tree (depending upon leaf–fruit ratio, etc.) than from week to week on a given tree. As indicated in Chapter V, the amounts of solids also vary from year to year. If one were aiming at a given soluble solids content because of some special use to which the apple was to be put, the soluble solids test would have considerable value.

Starch Content. As the apples mature on the tree the starch gradually decreases in the fruit. Attempts have been made to use the disappearance of starch as a criterion of when to pick.[309] Slices of apple are dipped in a solution of iodine–potassium iodide for one minute and the blue staining of the starch grains is used as an index of the amount of starch present. While this test has been recommended as being very useful in some sections it has not been found to be very reliable in the United States. The disappearance is so irregular

[309] J. E. Britton, D. V. Fisher, and R. C. Palmer, *Can. Dept. Agr. Farmers' Bull., 105,* 1941.

from apple to apple of apparently the same maturity that the test is very hard to interpret.

Rate of Respiration. In the discussion of respiration of apples it was pointed out that many apple varieties respire at different rates with changes in the age of the fruit. Attempts have been made to correlate the time of the respiratory rise with the proper time of picking. English work[310] has indicated that some varieties should be picked just before the climacteric rise begins. Some work done in Canada with McIntosh indicated that McIntosh should be picked after the climacteric rise.[311] However, work done at Ithaca, New York, has indicated that McIntosh had almost dropped its full crop by the time the climacteric was passed on the tree. This emphasizes that the purposes for which the fruit is to be used may have some bearing on when it is picked according to the respiratory curve. Work at Cornell has indicated that McIntosh should be picked just when the climacteric rise begins. In fact, this index was the most valuable single index of when to pick McIntosh although obviously this test is only of experimental interest since it is not adaptable to the orchard. With varieties like Rhode Island Greening or Northern Spy this index seemed to be of less value. It might be generalized that with varieties that have a sharp and marked rise in respiration or a distinct climacteric peak respiration measurements might have real value in determining when to pick for experimental purposes.

Some workers have leveled criticism at this technique because it did not represent the true respiration rate on the tree. This criticism was discussed in Chapter VI.

Apparently apples respire faster after removal from the tree than they do on the tree. While actual respiration studies were not made, ripening was found to be more rapid in detached fruits than in attached fruits when both were studied at the same temperature.[311a] This would indicate that if apples cannot be stored promptly after harvest, they might better be left on the tree. This would assume, of course, that fruit drop had not become a problem and the grower was forced to pick the fruit.

Days from Full Bloom. It is well known that different varieties of apples have different length growing seasons. For example, in a

[310] F. Kidd and C. West, *Sci. Hort., 5,* 78 (1937).
[311] W. R. Phillips, *Sci. Agr., 19,* 66 (1938).
[311a] Fisk Gerhardt, *Proc. Wash. State Hort. Assoc., 43,* 57–59 (1947).

given year it may require one variety 125 days to mature after full bloom and another 150 days to mature. Some investigators use this fact as a basis of recommending when a given variety should be picked.[312] [314] For example, it has been recommended that McIntosh be harvested 135 to 140 days from full bloom[314] with a minimum period of 130 days.

If this test of maturity could be proven to be really valid it would be one of the most useful and most easily used. There is a real question as to its actual validity, however. While it is claimed that the period from full bloom to harvest is fairly constant for a given variety in various sections and from season to season[314] there seem to be some variations from season to season with a given variety. One study in New York[312] gave an elapsed period of 127 days for McIntosh. Studies at Ithaca have shown a range from 125 to 157 days. In 1945 there was an abnormally early blooming season. McIntosh was in full bloom April 19th to 24th and there followed a very cool period of a month or more. They were harvested 157 days after full bloom. See Table 21.

Some of the studies made on this point have been open to criticism in that a record was only kept of blooming time and when the apples were harvested. A critical study of the point should involve actual storage of the fruit to see at which picking date the fruit actually kept in the best condition.

In some sections of the country the climate may be constant enough from season to season to make use of this test. However, careful studies with other fruits such as pears, apricots, and prunes have shown little value for this test.[315] When temperature records were kept and heat units were calculated a better job of prediction was made. A heat unit has been defined as one degree Fahrenheit per day above a given base temperature such as 45°F. (7°C.). The number of heat units was found to be dependent upon how far above 45°F. the temperature was and how long it remained above 45°F. Heat units were calculated from continuous thermograph records in a number of different orchards. When heat unit calculations were taken into consideration it was possible to predict the proper date of

[312] H. B. Tukey, *Farm Research*, Oct., 1942, p. 3.
[313] H. B. Tukey, *Proc. Am. Soc. Hort. Sci., 40,* 133 (1942).
[314] M. H. Haller, *U. S. D. A. Circ., 711,* 1944.
[315] R. Brooks, *Blue Anchor, 22,* 17 (1945).

TABLE 21. Comparison of Maturity Indices of McIntosh Apples at Harvest Time

Harvest date	Firmness, lbs.	Ease of separation	Ground color, No.	Surface color, %	Days from full bloom	Soluble solids, %
			1941			
9/3	17.1	Medium	2–2.5	30	117	11.3
9/10	16.0	Easy	2–2.5	40	124	11.6
9/17	16.0	Easy	2.5–3	60	131	12.7
9/24	15.3	Easy	2.5–3	75	138	13.2[a]
10/1	12.7	Easy	3	85	145	13.2
10/9	13.3	Very easy	4	95	152	13.4
			1942			
8/27	20.0	Medium	1.5–2	50	114	11.0
9/3	19.1	Medium	2	60	121	11.0
9/10	17.4	Medium	2	60	128	11.2
9/17	16.8	Easy	2.5–3	75	135	11.3[a]
9/21	17.2	Easy	3	85	142	11.8[a]
9/24	17.3	Easy	3	85	145	12.0
10/1	15.5	Easy	3–4	90	152	12.0
10/8	13.6	Very easy	4	95	159	11.8
			1943			
8/30	20.3	Difficult	1.5	25	98	11.0
9/3	19.8	Medium	2	30	102	11.1
9/10	18.4	Medium	2	40	109	11.2
9/17	18.0	Medium	2–2.5	75	116	11.6
9/21	17.4	Medium	2.5–3	90	120	12.0[a]
9/24	17.1	Medium	3	90	123	11.7
9/28	16.6	Easy	3–4	95	127	12.0
10/1	15.7	Very easy	4	95	130	12.2
10/5	16.0	Very easy	4	95	134	13.2
			1944			
8/30	20.2	Medium	2	10	105	10.5
9/6	20.7	Medium	2	15	112	10.4
9/13	20.3	Medium	2	28	119	10.8
9/19	17.3	Easy	2	28	125	11.8
9/22	15.8	Easy	2	40	128	11.7[a]
9/26	16.4	Very easy	2–2.5	60	132	12.4
9/29	15.5	Very easy	2–3	60	135	12.1
10/6	14.4	Very easy	3	70	142	12.9

Table continued

TABLE 21 (*continued*)

Harvest date	Firmness, lbs.	Ease of separation	Ground color, No.	Surface color, %	Days from full bloom	Soluble solids, %
			1945			
9/10	16.8	Medium	2	25	141	11.0
9/17	16.5	Medium	2.5	25	148	—
9/24	17.7	Medium to easy	2.5–3	50–75	154	11.0
9/27	17.3	Medium to easy	2.5–3	50–75	157	12.2[a]
10/1	16.7	Easy	3–4	50–75	164	12.8
10/5	16.9	Easy	4	80	168	13.2

[a] Lot which kept best in storage.

harvest of pears within 2 days 55% of the time, within 4 days 60% of the time, and within 6 days 80% of the time. This study indicated that even local orchard differences like cultural methods could influence the value of this index of maturity.

It may be concluded then that this test may have some value in some sections but only if careful temperature records are kept over a period of years to indicate what the variations are from year to year as affected by prevailing temperatures. Without these temperature records the test would seem to have only limited value.

Development of Red Color. The amount of surface color or red coloration on the colored varieties of apples is sometimes used as a criterion of when to pick. It is true that the amount of red color increases as the apples mature and growers desire the maximum amount of red color possible before picking. However, certain varieties and particularly the red strains of some varieties may be fully colored with red several weeks before the proper time of picking. On the other hand, some varieties in some seasons may not have very much red coloration at the time they should be picked, because of climactic factors or fertilizer practices. This index of picking maturity is of little or no value, except that a grower might with good reason wait as long as feasible for the apples to develop as much red color as possible before harvest.

Seed Color. As the seeds mature inside an apple they turn brown or black. This change was utilized by pioneers in the apple industry as one of the best indices of when to pick. The seeds of many late varieties, however, like Northern Spy are often fully brown some little time before the optimum picking date. The time of coloration

often varies from season to season so much that it makes the test of little or no value. It is true however, that most late varieties usually have fully brown or black seeds before they are ready for harvest.

Fruit Size. Most varieties of apples keep increasing in size to some extent as long as they hang on the tree.[303] Fruits of early varieties such as Yellow Transparent and Williams are growing rapidly as they approach maturity and may increase as much as 2% per day in volume during the harvest season. Fruits of early fall apples such as Jonathan may increase as much as 1% in volume per day during the harvest season, while fruits of the late varieties such as Winesap that mature during cool weather may not increase more than 0.5% per day.

Hence, under conditions favorable for growth allowing the fruit to hang on the tree as long as possible may result in increases in crop volume.[314] However, the use of fruit size is of limited value in determining when to pick. It is true that the grower would like to let the fruit get just as large as possible. Obviously, however, if the season has been dry the fruit may all drop off before it reaches a good commercial size. On the other hand, fruit with a wide leaf–fruit ratio may be too large for good commercial purposes and yet should be allowed to hang on the tree to develop the proper complement of sugars and other quality factors.

Corking Over of Lenticels. As apple fruits mature on the tree the lenticels become filled with cork cells in many cases. There is also a development of wax on the surface of the fruit that has been described in Chapter VI. These changes are not sufficiently discernible however to make them of much value in determining the proper time for harvest.[314]

B. Factors Affecting Fruit Quality

Quality is used in this discussion mainly to describe the attributes of the apple that pertain to edibility. It may refer to the characteristics of fruit to be eaten in the fresh or cooked condition. For example, Rhode Island Greening might have the right "quality" for cooking purposes and yet be entirely too sour for eating. There is also the human factor in any discussion of quality. Ordinarily Rhode Island Greening would not be classed as a dessert apple to be used for eating out of hand yet there are a few people who prefer it for eating

to the variety Delicious which is ordinarily classed as being a dessert apple.

Quality is a very broad term and in this discussion it is confined only to the factors involving edibility. Some would say that defects like scab or other diseases would be involved in "quality." The authors would prefer to say that defects of this type affected fruit "condition" and not quality. However, it might facetiously be added that the presence of worms in an apple might well affect the eating quality!

There are a number of factors which may affect the eating quality of apples whether the fruits are to be used as fresh or cooked fruit. Many of these factors are chemical or anatomical and some may be purely psychological.

TABLE 22. ACID–ASTRINGENCY–SUGAR RATIOS[a] FOR VARIETIES OF APPLES ANALYZED IN YEARS SHOWN[318]

Variety	1922	1923	1924	1925
Baldwin	1:0.15:18.4	1:0.21:23.5	1:0.29:26.7	1:0.22:24.0
Black Ben	1:0.25:15.8	1:0.24:22.8	1:0.25:24.8	1:0.21:20.6
McIntosh	1:0.17:16.6	1:0.19:17.5	1:0.17:24.8	1:0.28:25.4
Rome Beauty	1:0.24:28.9	1:0.18:30.9	1:0.31:31.1	1:0.36:31.9
Tompkins King	1:0.18:19.2	1:0.27:31.0	1:0.24:23.6	1:0.31:32.3
Yellow Transparent	1:0.28:11.6	1:0.16:6.73	1:0.31:13.8	1:0.15:15.7

[a] Acids expressed as malic acid; astringency expressed in terms of the tannin factor; sugars expressed as invert sugar.

Chemical Determinants of Quality. Careful chemical studies of the apple fruit have not been very helpful in determining exactly how chemical constitution affects eating quality. While taste as judged by different individuals varies it still seems to be a more reliable index of quality than any chemical measures.[315a] For dessert quality the amount of *sugar* present is an important consideration. It is probably more important than the amount of *acid* present in determining eating quality.[315a] However, the amount of sugar *as such* may not be as important as one might think. One variety of apple might have slightly more sugar than a second variety and yet be more sour to the taste. The greater sourness in this case would probably be due to the greater amount of acid present. This factor is called the *acid–sugar ratio.* Table 22 indicates the acid–sugar ratio of some common apple varieties. It should be noted that some apple varieties with the same

[315a] J. L. St. John and O. M. Morris, *J. Agr. Research, 39,* 623 (1929).

acid–sugar ratio do not have the same eating quality. For example, Rome Beauty has about the same acid–sugar ratio as McIntosh which is much higher in quality.[316] It might be concluded that the acid–sugar ratio is of some importance in determining eating quality but that other factors often outweigh this one factor.

The kind of sugar present in apples may have some bearing on the eating quality. If a variety has a higher percentage of fructose than another variety with the same total sugar content, the apple might taste somewhat sweeter.[317]

The *astringent materials* in apples play a considerable role in determining eating quality. A variety of crab apples might have the same acid–sugar ratio as a variety of eating apples and yet be too astringent to eat. Hence the *acid–astringency–sugar ratio* has been used to describe the relative quality of certain varieties of apples and apple juices.[318] If all three of these factors vary from season to season or from variety to variety in about the same degree no difference may be noted in eating quality. If one or two factors vary considerably from season to season, a marked effect on eating quality may be noted. For example, it has been found in apple juices that following seasons of high light intensity and duration and plenty of warm weather the relative astringency was low and hence the apple juice had a sweeter and milder taste than in other seasons.

Much of the pleasure of eating an apple is due to its *odor*. It has been pointed out in other sections that the chemical constituents responsible for odor were various esters, essential oils, and aldehydes. The McIntosh has a very distinctive odor and hence this contributes to its high eating quality. If one holds his nose while eating a McIntosh it does not have the typical McIntosh flavor. Since odor contributes so much to the quality of apples it is important that there be no cross contamination of the fruit with other odors. The apple absorbs certain odors very readily. For example, when apples are stored in a chamber where there is a great deal of surface mold, they absorb the musty odor of the atmosphere, and develop a "musty" flavor. Sometimes the pine wood odors emanating from the yellow pine construction or from the box wood contribute sufficient pine odor to the atmosphere to impair the flavor of the fruit. Apples are sometimes sold at

[316] J. K. Shaw, *Mass. Agr. Expt. Sta. Bull. Rept., 23,* 177 (1911).
[317] F. Thompson and A. C. Whittier, *Proc. Am. Soc. Hort. Sci., 9,* 16 (1913).
[318] J. S. Caldwell, *J. Agr. Research, 36,* 289 (1928).

reduced prices on the market in late spring because of the strong pine flavor which they have following storage in certain storage rooms. When apples are stored with certain other products like potatoes or onions they are very likely to absorb potato or onion odors and hence

TABLE 23. Some Factors Affecting Preservation of Quality

	Orchard factors	Postharvest factors	Storage factors
Sugars	Healthy leaf surface Light Water supply Temperature Leaf–fruit ratio Time of harvest	Prompt storage Amount bruising	Temperature Ethylene Carbon dioxide Oxygen
Acids	Healthy leaf surface Leaf–fruit ratio	Prompt storage	Temperature Ethylene Carbon dioxide Oxygen
Pectic materials	Summer weather?	Prompt storage	Temperature Ethylene Carbon dioxide Oxygen
Astringent materials	Weather		
Odor	Weather?	Prompt storage	Temperature Ethylene Carbon dioxide Oxygen Odor contamination
Water content	Weather	Prompt storage	Temperature Relative humidity Vapor pressure deficit Waxing Special wraps
Anatomical factors	Weather Leaf–fruit ratio Culture		
Psychological factors	Red color Size Bruising Leaf–fruit ratio Weather Culture		

be off flavor. For this reason apples should never be stored with products like potatoes for any extended period of time. While the apple may lose some of the odors which contaminate it upon removal from storage it may often require several days at room temperature for all

of the foul odors to leave. Cases have been observed when apples were stored in severely molded storage chambers that the apples never lost the foul odors.

Air purification is sometimes an aid in removing some types of odors in the apple storage and hence improving fruit quality. Ozone has been found to be of little value in air purification for this purpose except in the destruction of surface molds. Purification of the air with activated carbon has shown considerable benefit from this standpoint with certain odors.[319]

The actual *water content* of an apple may affect its eating quality. If an apple is badly shrivelled it does not have the proper quality. It is said to lack "crispness and juiciness."

Anatomical Determinants of Quality. It has been pointed out in other sections that the cells of the apple are cemented together with pectin compounds. As this protopectin is hydrolyzed the cells become less firmly cemented together. When one bites into an apple in which there has been little hydrolysis of the protopectin the cells burst and the juice spurts out into one's mouth. If much of the protopectin has broken down into soluble pectin and the cells slough apart when the fruit is bitten into the cells slide across each other and are not ruptured. Such an apple is said to be mealy and low in eating quality. This factor is partly chemical and partly anatomical because the protopectin is in the middle lamella of the cells and when the middle lamella is broken down the cells slough apart.

Some varieties of apples may have eating quality different from others because the cell walls of the fleshy portion of the fruit are thicker. The cooking varieties may very well have thicker walls. For some types of applesauce the cells should separate very readily while for baking this is not important. It has been found that apples with a large pith area are less desirable for sauce since the small elongated pith cells with no fibrous tissue adhere firmly to each other.[320] Some workers have preferred varieties with large cells for sauce purposes.[320]

Psychological Determinants of Quality. The amount of *red color* on fruits is sometimes a psychological factor determining eating quality. To be sure a yellow variety might actually have higher eating quality than a red colored one—yet yellow apples are often discriminated against by some consumers because they associate them with

[319] C. R. Gross and R. M. Smock, *Refrig. Eng., 50,* 535 (1945).
[320] A. B. Milam and H. B. Gardner, *Oregon Agr. Expt. Sta. Bull., 124,* 1915.

cooking apples. One reason some of the newer yellow varieties of high eating quality do not sell well in some markets is because people do not *think* they will taste as well.

The *size factor* may be of some psychological significance in determining eating quality. People often think that large apples will taste better than small ones. Actually the small ones may be of higher eating quality.

Bruising may directly affect eating quality or it may be purely a psychological factor. Badly bruised apples do not look very appetizing.

CHAPTER VIII

PRESTORAGE TREATMENT OF APPLES

A. Cleaning Apples

Apples may be cleaned either by wiping or washing. Cleaning is sometimes necessary because of their dirty appearance. "Drop" apples that are to be sold as fresh fruit are often washed if they are covered with dirt. Occasionally apples that are grown near a railroad must be washed to remove excessive deposits of soot. More commonly cleaning is done to remove spray deposits.

Apples are commonly sprayed with lead arsenate to control chewing insects such as the codling moth and apple maggot. A relatively new material called DDT (dichlorodiphenyltrichloroethane) has given very good results in codling moth control and is being increasingly used in apple orchards. Occasionally a cryolite spray containing fluorine is used. Since these are stomach poisons for the chewing insects, there is a possibility that sufficient residue may remain on the fruit at harvest time to be poisonous to humans. Occasionally nicotine sulfate is used in combination with bentonite clay to control codling moth. Residues from such sprays are sometimes present in sufficient quantity to require removal merely from the standpoint of appearance if not from the standpoint of human toxicity.

The Food and Drug Administration, (now part of the Federal Security Agency), sponsored a law in 1906 which prescribed the amounts of lead and arsenic that could legally remain on the fruits at harvest time. The ruling was more or less disregarded by apple handlers until 1926, when an embargo was threatened by England against American apples. This threat grew out of the fact that several persons had presumably become sick after having consumed heavily sprayed American apples.

Just how toxic the lead and arsenic residues on apples may be is a moot question. The Council on Foods of the American Medical Association has ruled that no food shall contain more than 2 parts per million of lead.[321] This tolerance is lower than the Federal tolerance.

[321] Anon., *J. Am. Med. Assoc., 108,* 1178 (1937).

The attitude of the Council is that even though experiments by the Public Health Service[322] have shown no deleterious effects on health of humans who have consumed heavily sprayed apples an occasional individual may be sensitive to small quantities of lead or arsenic. The United States Public Health Service has conducted more exhaustive tests than any other agency in this connection.[322] Their findings may be summarized as follows. There seems to be little or no danger from lead or arsenical poisoning from eating sprayed apples even over a period of years. The real danger in connection with this spray material lies in the fact that workmen may inhale quantities of the dust of the material in preparing the sprays. The only poisoning that was found was in such individuals. Since this subject of possible

TABLE 24. TENTATIVE TOLERANCES FOR INSECTICIDES (1949)[322a]

Material	Grains per lb. fruit	Parts per million
Lead (as Pb)	0.050	—
Arsenic (as As_2O_3)	0.025	—
Fluorine (as F)	0.049	—
Parathion	—	2
DDT	—	5
Tetraethylpyrophosphate	—	No problem
Gamma isomer benzene hexachloride	—	3–5
Nicotine	—	No problem

toxicity is such a moot question, it is likely that the tolerance may be lowered or raised from time to time (see Table 24).

The toxicity of DDT to humans is not yet fully known (1950). To date no authenticated cases of poisoning have been reported from having eaten DDT sprayed apples. No good method has yet been found for removal of this material from apples without injuring the skin. The unofficial tolerance that prevailed in 1949 was 5 parts per million of the fresh weight of the fruit.

Methods of Cleaning. The simplest method of cleaning either of dirt or of spray residues is by wiping. Wiping machines may remove most of the visible dirt and spray residue. If excessive residues of lead arsenate are present in the calyx or stem end of the fruits, of course, wiping may not remove enough to bring the fruit down below the legal tolerance.

[322] R. H. Heeren and H. B. Funk, *U. S. Public Health Rept., 52,* 8 (1937).
[322a] A. J. Lehman, *Assoc. Food and Drug Officials of U. S., 13,* 65–70 (1949).

Washing with water will remove dirt, if dirt is the only material to be removed. However, if lead arsenate is present, hydrochloric acid must be used. Commercial grade hydrochloric acid (32% actual acid) is used. About 2.8 gallons of commercial acid are added to 100 gallons of water to get a 1% solution. The strength of the acid must be titrated frequently to make sure that it is strong enough. If the acid is too strong injury to the fruit is likely to result.[323]

Various types of machines are used in acid-washing the fruit. In some machines the fruits merely float through the acid bath and are occasionally submerged by paddles. This type is called the flotation washer. In other machines the fruits are not only brushed while being washed but are flooded with acid as they are brushed. This type is called the "under-brush-flood washer." The fruits are usually in the acid from 30 to 60 seconds in the latter type of machine and from 60 to 120 in the former.[323] Occasionally when spray removal is difficult, wetting agents are used in the acid. With very waxy fruit or with oil sprayed fruit it may be necessary to use odorless kerosene or a very light mineral oil in heated acid solutions. Such a washing treatment is only effective when the mixture is heated to at least 90°F. (32°C.) and a flood or flood-brush type of machine is used.[323] Heating should never exceed 110°F. (43°C.) or injury will result to the fruit. Dangers in excessive removal of the natural wax by means of emulsifying agents and heating have already been pointed out in Chapter VI.

Sodium silicate is often used to remove residues that contain lead arsenate and oil (fish or mineral) or it may be used when the fruit is especially waxy. It is often used in the Pacific Northwest in series or in tandem with an acid wash. The silicate wash is used first to loosen the residues and then the acid dissolves the lead arsenate. Sodium silicate is used at concentrations of 40 to 80 pounds to 100 gallons of water at temperatures of 90° to 110°F. in a flood or brush-flood type of washer.

After the fruit is washed with any of these cleaning solutions it is necessary that it be rinsed. For effective rinsing, from 3 to 4 gallons of fresh water per bushel of fruit washed should be added to the rinse tank as a spray on the fruit as it leaves the tank. Rinsing is doubly important when detergents, mineral oil, or sodium silicate are

[323] M. H. Haller, E. Smith, and A. L. Ryall, *U. S. D. A. Farmers' Bull.*, 1752 1943.

used. When the rinse water turns red to litmus paper or is sour to the taste it should be changed or lime added to neutralize the acid.[323]

If the fruit is sound and the washing and rinsing operations are carefully done, drying the fruit is not absolutely essential. Many machines have absorbent cloths which pass over the rotating fruit to remove excess water after the rinsing process is completed.

The efficiency of the washing operation seems to depend upon: (*a*) the amount of residue present on the fruit; (*b*) climatic and cultural conditions—in hot growing section there is more natural wax on the fruit and removal is more difficult; (*c*) variety and maturity of the fruit (some varieties produce more natural wax than others and the riper fruit is, the more wax it has at harvest time; roughness of skin, and not only the quantity but also the quality of the wax, differ among varieties); (*d*) materials used in the spray program (the use of fish oil or cryolite in the spray program makes residue removal more difficult; nicotine–bentonite spray residues are difficult to remove if present in excessive quantities—sodium silicate must be used for this type of residue); (*e*) type and concentration of solvent used; (*f*) length of washing treatment; (*g*) amount of agitation during the washing operation; (*h*) temperature of washing solution.

Since fruit cleaning by washing is an added operation that is rather expensive (from one to 5 cents per bushel) and results in some bruising to the fruit, apple growers would obviously like to avoid the operation if possible. The real hope of the future lies in the development of spray materials that are toxic to insects and not to humans. Research indicates that there is hope in this connection—although secondary effects of such insecticides on beneficial insects and on humans must be thoroughly investigated.

B. Grading Apples

Most apples are graded before being sold although some may be sold "tree run." Even the latter may be packed by someone other than the grower himself. Most apple "grading machines" move the apples past people who do the actual grading by eye. On some machines the apples are actually turned so that inspection may be rather complete without hand turning the apples, but still other graders merely have continuous belts which move past the people doing the grading. The persons doing the grading place the apples on different belts which carry them to the sizer. The sizing machines separate

the apples on various principles, some do it on a weight basis, and others on the actual diameter of the fruit. Some packers of soft varieties like McIntosh may have the sizing done by eye or inspection, since any machinery handling is likely to bruise them.

Most states have grading laws for apples which more or less follow the United States grading standards. Some states, particularly those in the Pacific Northwest, have their own particular grade names and standards. The grading laws of most states state that all apples sold in closed containers must be marked as to variety, grade, size range, or count of the fruit in the box, quantity of the contents or the net weight, and the name and address of the packer or repacker.

The apple grades in the Pacific Northwest are as follows:

	Combination Grades:
Extra Fancy	Extra Fancy and Fancy
Fancy	Extra Fancy, Fancy, and C Grade
C Grade	Extra Fancy and C Grade
Hail Grade	Fancy and C Grade

The U. S. grades are as follows:

	Combination Grades:
U. S. Fancy	U. S. Fancy and U. S. No. 1
U. S. No. 1	U. S. No. 1 and U. S. Commercial
U. S. Commercial	U. S. No. 1 and U. S. Utility
U. S. Utility	
U. S. Hail Grade	
Unclassified	

For the details on these grades it is suggested that a copy of the U. S. Grades as outlined by Federal and State laws be obtained. The grades are merely outlined herein to give a general picture of the grade requirements. Careful legal definitions of the various descriptions of defects allowable in the various grades are given in the legal standards.[324]

The first three grades (U. S. Fancy, U. S. No. 1, and U. S. Commercial) are fruit free from "damage" and differ only as to the amount of red color present. The U. S. Utility grade includes fruit free from "serious damage." A brief outline of what constitutes "damage" and "serious damage" appears in Table 25, which summarizes some of the main features of the grade requirements. The U. S. Hail grade provides for apples of U. S. No. 1 which have been

[324] Anon., *N. Y. State Dept. Agr. and Markets Circ.*, 544, 1937.

TABLE 25. TABULATION OF DEFECTS PERMITTED IN U. S. GRADES FOR APPLES[324]

Injury or defect	U. S. Fancy, U. S. No. 1, U. S. Commercial	U. S. Utility
Decay, cork spot, internal browning, internal breakdown scald, freezing injury, worm holes, other unhealed insect injury	None	None
Dirt, spray residue	Practically none	None noticeable by casual examination
Visible watercore	None	0.5 in. diameter
Broken skin, bruises	Incident to proper handling and packing	Must not seriously detract from appearance or seriously affect the keeping quality
Stems and calyx cracks	1 crack, well healed, 0.25 in. length	Well healed, 0.5 in. length
Russeting Note: The russeting permitted is in addition to one of the other listed defects or any combination thereof the seriousness of which does not exceed the maximum allowed for any one	Russeting as follows permitted: Any russeting which is not excessively rough on Roxbury Russet and similar varieties. Russeting on other varieties covering a total area of not more than 25% of surface in aggregate except that: (*1*) not more than 10% in aggregate of smooth solid russeting permitted unless russeting within or continuous with stem basin or calyx cavity when an additional 15% is permitted provided total does not exceed 25% in aggregate; (*2*) not more than 15% of slightly rough russeting permitted if confined to stem basin or calyx cavity or continuous with, or not over 0.5 in. area if not continuous with russeting in stem basin or calyx cavity; (*3*) not more than 0.25 in. area of rough russeting outside of russeting well within stem basin which is not readily apparent	Russeting as follows permitted: Any amount of russeting on Roxbury Russet and similar varieties. On other varieties any amount of smooth netlike russeting, or one half of surface in aggregate of smooth solid russeting, or rough or barklike russeting which detracts from appearance of fruit to the extent of smooth solid russeting permitted
Sprayburn, sunburn	If no blistering or cracking of skin and discoloration blends into normal color of the fruit, or if can be classed as russeting	Must not seriously detract from appearance or seriously affect the keeping quality

Table continued

TABLE 25 (*continued*)

Red skin spot, bitter pit, Jonathan spot	1/10 surface if heavy, 1/5 if scattered 3 indistinct spots	Any amount Spotting 1/10 surface if not materially deforming or disfiguring fruit
Fruit, York, King David, drought spots, hard dry bruises	0.5 in. diameter aggregate if superficial	Affecting 1/10 surface if not materially deforming or disfiguring fruit
Limb rubs, light brown	1 in. diameter aggregate	1/10 surface aggregate
Limb rubs, dark or black scars	0.5 in. diameter aggregate	1/10 surface aggregate
Hail marks	0.5 in. diameter aggregate if superficial and skin not broken	1/10 surface aggregate if not materially deforming or disfiguring fruit; or 0.5 in. diameter aggregate and well healed if skin broken
Apple scab, apple blotch, cedar rust	0.25 in. diameter aggregate (scab spots corked over)	0.75 in. diameter aggregate (scab spots corked over); scattered over 1/3 of surface
Sooty blotch, fly speck	Thinly scattered over 1/10 surface, or 0.5 in. heavily concentrated	
Healed stings	2 to apple, dry and corky, not over 1/8 in. diameter exclusive of any discolored ring	5 to apple, dry and corky
San Jose scale	3 heavy marks on green surface, 5 to 10 on red surface, depending on prominence; marks in calyx of well-colored apples not objectionable; a few scale permitted in calyx	Marks confined to 1/10 surface if thick or grouped; 1/3 if thinly scattered; a few scale
Shape	Fairly well formed	Not seriously misshapen or deformed

injured by hail (no broken skin due to hail is allowable here). The Combination grades are provided in case a packer wants to mix two grades. When such grades are packed at least 50% of the apples in any container must meet the requirements of the higher grade in the combination. The Unclassified mark is given ungraded apples; not more than 15% of the apples in this grade may be culls, however.

In addition to the foregoing requirements for U. S. Fancy and U. S. No. 1, each apple of these grades must have the percentage of color shown in Table 26.

TABLE 26. Percentage of Red Color Required for Apples of U. S. Fancy and U. S. No. 1 Grades[324]

Variety	U. S. Fancy, %	U. S. No. 1, %
Solid red		
Winesap	50	25
Gano	50	25
Striped or partially red		
McIntosh	50	25
Delicious	33	15
Baldwin	33	15
Ben Davis	33	15
Northern Spy	33	15
Rome Beauty	33	15
Tompkins King	33	15
Wagener	33	15
Wealthy	33	15
Stark	25	10
Hubbardston	25	10
Williams	33	Tinge of color
Gravenstein	25	Tinge of color
Red Astrachan	25	Tinge of color
Red cheeked or blushed		
Winter Banana	Blushed cheek	None
Other red cheeked or blushed varieties	Blushed cheek	None

"For the solid red varieties the percentage stated refers to the area of the surface which must be covered with a good shade of solid red characteristic of the variety, except that an apple having color of a lighter shade of solid red or striped red than that considered as good shade of red characteristic of the variety may be admitted to a grade, provided it has sufficient additional area covered so that the apple has as good an appearance as one with the minimum percentage of good red characteristic of the variety required for the grade.

"For the striped red varieties the percentage stated refers to the area of the surface in which the stripes of good shade of red characteristic of the variety shall predominate over the stripes of lighter red, green, or yellow. However, an apple having color of a lighter shade than that considered as good shade of red characteristic of the variety may be admitted to a grade, provided it has sufficient additional area covered so that the apple has as good an appearance as one with the minimum percentage of stripes of good red characteristic of the variety required for the grade. Faded brown stripes shall not be considered as color except in the case of the Gray Baldwin variety."[324]

Tolerances for Preceding Grades. In order to allow for unavoidable variations incident to proper grading and handling, not more than a total of 10% of the apples in any container may be below the requirements of the grade, provided that not more than 5% shall be seriously damaged by insects and not more than one fifth of this amount, or 1%, shall be allowed for decay or internal breakdown.

When applying the foregoing tolerances to the combination grades no part of any tolerance shall be allowed to reduce, for the lot as a whole, the 50% of apples of the higher grade required in the combination, but individual containers may not have less than 40% of the higher grade.

The tolerances for the standards are on a container basis. However, individual packages in any lot may vary from the specified tolerances as stated below, provided the averages for the entire lot, based on sample inspection, are within the tolerances specified.

For a tolerance of 10% or more, individual packages in any lot may contain not more than one and one half times the tolerance specified, except that when the package contains 15 specimens or less, individual packages may contain not more than double the tolerance specified.

For a tolerance of less than 10%, individual packages in any lot may contain not more than double the tolerance specified, provided at least one specimen which does not meet the requirements shall be allowed in any one package.

Condition after Storage or Transit. Decay, scald, or other deterioration which may have developed on apples after they have been in storage or transit shall be considered as affecting condition and not the grade.

Size Requirements. The numerical count, or the minimum size, of the apples packed in a closed container shall be indicated on the package.

When the numerical count is marked on the container the apples shall not vary more than one-fourth inch in the transverse diameter.

When the numerical count is not shown the minimum size shall be plainly stamped, stenciled, or otherwise marked on the container in terms of whole inches, whole and half inches, whole and quarter inches, or whole and eighth inches, as 2.5 inches minimum, 2.25 inches minimum, or 2.625 inches minimum in accordance with

the facts. It is suggested that both minimum and maximum sizes be marked on the container, as 2.25 to 2.75 inches or 2.5 to 2.75 inches, as such marking is especially desirable for apples marketed in the export trade.

"Size" means the transverse diameter of the apple taken at right angles to a line running from the stem to the blossom end.

In order to allow for variations incident to proper sizing, not more than 5% of the apples in any container may not meet the size requirements, provided that when the maximum and minimum sizes are both stated an additional 10% tolerance is provided for apples which are larger than the maximum size stated.

C. Wrapping and Waxing Apples

Apples are often *wrapped* in box packing for several reasons. The wraps are usually impregnated with mineral oil and hence assist in the control of apple scald. The wraps help in the packing operation to make a tight package and hence result in lessened bruising. Practically all the wrapping of apples with paper is done in the Pacific Northwest and in California. This is largely due to the fact that their apples are shipped such long distances that the fruits must be tightly packed in the package.

Apples can be wrapped with special materials to lessen the amount of shrivelling in storage.[325,326] A number of materials such as aluminum foil, Pliofilm, and Cellophane have been used in wrapping for this purpose. Care must be taken that the wrap is not too impervious to the passage of oxygen and carbon dioxide or there is likely to be injury to the fruit. Some wraps when heat-sealed are practically perfect in reducing moisture loss but they are so impervious to the movement of all gases that anaerobic respiration is likely to occur. Another difficulty encountered with wraps is on scald-susceptible varieties. The wraps do not allow the diffusion away of the scald-producing gases and considerably more scald than usual may ensue. In some cases individual fruits may not be wrapped with the moisture-impervious material, but the box is merely lined with the material.[325] Figure 45 illustrates the effects of some of these wrapping materials in reducing weight loss in apples in storage. Off flavors were

[325] H. H. Plagge and T. J. Maney, *Ice and Refrig.*, *101*, 201 (1941).
[326] H. A. Baghdadi and R. M. Smock, *Proc. Am. Soc. Hort. Sci.*, *42*, 238 (1943).

encountered, however, with the most effective moisture barriers.[326]

Apples may be *waxed* for a number of reasons. Waxing has been found to reduce the amount of scald of susceptible varieties when certain wax emulsions are used.[327,328] Waxing improves the appearance

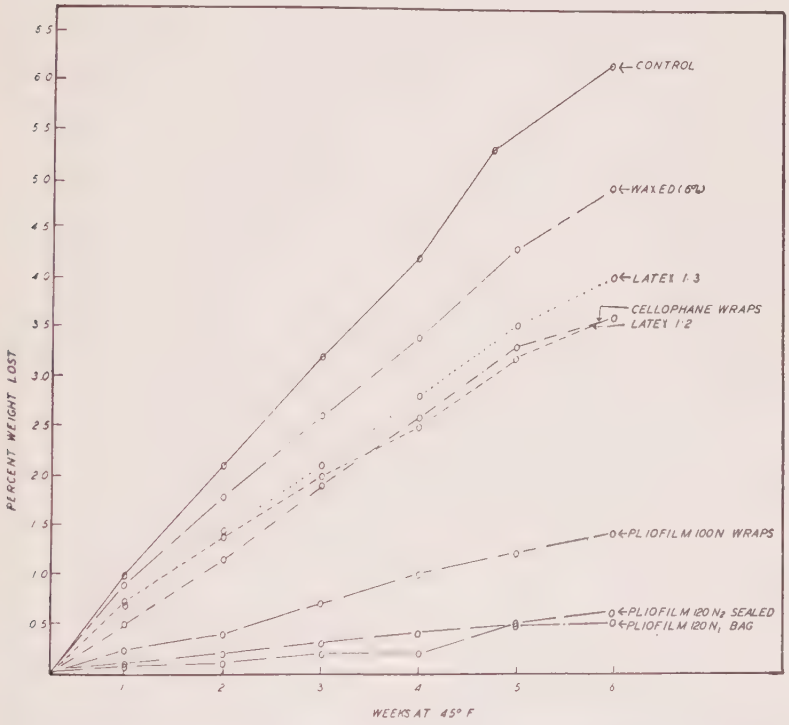


Fig. 45. Effects of various fruit coverings on the weight losses of Golden Delicious apples at 45°F. (7°C.).[326]

of some varieties. For example, Rhode Island Greening has a brighter green look after waxing even immediately following harvest time. Waxing reduces the moisture loss from apple fruits. With certain varieties like Grimes Golden and Golden Delicious waxing is of considerable benefit because these varieties normally have a rapid trans-

[327] R. M. Smock, and F. W. Southwick, *Cornell Univ. Agr. Expt. Sta. Bull.*, 813, 1945.

[328] C. W. Hitz and I. C. Haut, *Proc. Am. Soc. Hort. Sci., 36,* 440 (1939).

piration rate. Figure 45 illustrates the effects of a given dilution of a wax emulsion on weight losses in Golden Delicious.[329] Judicious waxing results in a slightly longer storage life because of its effect of inhibiting respiration.[330,331]

Water emulsions of paraffin and carnauba waxes are usually used in waxing apples. Besides the emulsifying agent certain other waxes are sometimes incorporated. The diluted emulsion is applied either by spraying it on the fruit or by dipping the fruit. The apples must then be dried. Ordinarily the fruits pass on rollers through a heater to dry the wax.

Care must be taken that excessive quantities of wax are not applied. If the wax is not sufficiently dilute the coating is so thick that oxygen and carbon dioxide cannot readily pass to and from the fruit. Too thick a coating of wax is likely to result in off flavors due to anaerobic respiration.

The apples must be reasonably clean when waxed or the wax merely seals in the dirt or excessive spray residue. If large quantities of lead arsenate residues remain on the fruit at the time of waxing, the emulsion is likely to be broken down during waxing. In such cases the apples should first be washed in acid and rinsed before being waxed. They do not have to be dried before waxing.

D. Carbon Dioxide Treatment of Apples

Carbon dioxide treatment involves the use of rather large quantities or concentrations of this gas and a rather low temperature. It differs from "controlled atmosphere" storage in that the period of treatment is much shorter, the concentration of carbon dioxide is higher, and the gas is supplied quickly and artificially. Carbon dioxide for this treatment is obtained either from dry ice (solid carbon dioxide) or from cylinders of carbon dioxide.

Carbon dioxide treatments of apples usually involve prestorage exposure to this gas for various reasons. One reason that has been suggested has been to extend the storage life of the fruit from the standpoint of firmness. Holding three varieties of apples for two days in about 40% carbon dioxide at an average temperature of about 50°F.

[329] R. M. Smock, *ibid.*, *37*, 448 (1940).
[330] R. M. Smock, *ibid.*, *33*, 284 (1936).
[331] L. L. Claypool, *ibid.*, *37*, 443 (1940).

(10°C.) and then placing them in 70°F. (21°C.) air resulted in somewhat longer keeping. These apples kept about one pound firmer as indicated by the pressure tester than similar apples held continuously in 70°F. air and about 0.75 pounds firmer than similar apples held at the same temperature (50°F.) but without carbon dioxide during the two day treatment period.[332] Up to the present time (1950) no commercial use has been made of this treatment for this purpose to the authors' knowledge. Carbon dioxide treatment prior to controlled atmosphere storage has not given results striking enough to justify the practice.[333]

Prestorage treatments with carbon dioxide have been found to reduce the amount of soggy breakdown in apples.[334,335] Treatment with 30–60% carbon dioxide at 32°F. (0°C.) for 3 to 10 days has resulted in slower development of the scald disease on Rhode Island Greening in storage.[336]

Commercial use of carbon dioxide treatments for apples would involve the use of relatively gastight rooms for the treatment. It is doubtful if this treatment will come into commercial usage with apples as widely as it has with the small fruits and some of the stone fruits like sweet cherries. The usual treatment for scald control with Greening is 50% carbon dioxide for five days at 32°F.[336a] With varieties like Baldwin and McIntosh there is danger of some injury when this much carbon dioxide is used for five days. It has also been found that in years of extreme susceptibility to internal browning, this trouble may be increased by use of 50% carbon dioxide for six days.[336b] The cost of this treatment is calculated to be about two cents per bushel.[336a]

E. Precooling of Apples

Precooling refers to the rapid removal of field heat prior to shipment or storage. Precooling is most commonly done with fruits prior

[332] C. Brooks, *ibid., 37,* 463 (1940).
[333] R. M. Smock and A. Van Doren, *Cornell Univ. Agr. Expt. Sta. Bull.,* 762, 1941.
[334] C. Brooks and C. P. Harley, *J. Agr. Research, 49,* 55 (1934).
[335] F. Gerhardt and B. D. Ezell, *Proc. Wash. State Hort. Assoc., 39,* 100 (1934).
[336] S. A. Pieniazek, *Plant Physiol., 20,* 313 (1945).
[336a] S. A. Pieniazek, E. P. Christopher, and L. H. McElroy, *Proc. Am. Soc. Hort. Sci., 48,* 81 (1947).
[336b] R. M. Smock and F. W. Southwick, *Cornell Univ. Agr. Expt. Sta. Bull.,* 843, 1947.

to shipment in refrigerator cars or refrigerated boats for the export trade. Precooling of apples prior to shipment is not practiced nearly as much as it is with the other deciduous fruits. This is partly due to the fact that most apples are harvested and shipped at a time of year when outside temperatures are not as big a factor as they would be with crops like California plums and cherries. On the other hand some apples, such as California grown Gravensteins, are picked and shipped during the heat of summer. Even then, however, precooling is not commonly practiced prior to shipment except for the export trade.[336c]

The rate of precooling of apples depends upon the nature of the container, the amount and nature of liners and pads used, the presence or lack of fruit wraps, the amount of field heat present, the temperature of the air used in cooling, and the velocity and volume of the air used in precooling. For example, unwrapped apples in boxes required 20% of the time to be precooled to 35°F. (1.6°C.) in 32°F. (0°C.) air as wrapped fruits. The time necessary to cool apples to 34°F. (1.1°C.) in 32°F. (0°C.) air was 84 hours in air with little circulation. When air circulation at the rate of 250 feet per minute was used, the cooling time was reduced to 48 hours. The use of 25°F. (—3.9°C.) air for precooling apples with "rapid circulation" should result in a 40% saving in time as compared to cooling in 32°F. (0°C.) air with little circulation.[336c]

At the present time there is little precooling of apples prior to storage. In a properly equipped and operated storage there would seem to be little advantage in precooling since field heat should be removed in about five days. It is true, however, that there are storages in which complete removal of field heat is delayed as long as a month or more. There are certain special situations in which precooling of apples prior to storage might be of some benefit.

There are several methods of precooling that could be practiced prior to storage. One method would involve the use of a special room which utilized high velocities and volumes of very cold air. This general method has been well described by Allen and McKinnon.[336c] Precooling in refrigerator cars is also described.[336c] Another method is hydrocooling. This involves the immersion of the fruit in water close to the freezing point. Because of the immersion of the fruit in the water, field heat is removed very rapidly. In one installation for apples with a

[336c] F. W. Allen and L. R. McKinnon, *Calif. Agr. Expt. Sta. Bull.*, 590, 1935.

6 ft. by 100 ft. concrete tank with a revolving current of water supplied at the rate of 800 gallons per minute, field heat of 58°F. (14.2°C.) was reduced to 37°F. (2.7°C.) in fifty minutes. A ten-horse power compressor was used to cool this water.[336d] Hydrocooling is practiced with loose fruit (*i.e.* unpacked). No information is available as to the amount of bruising that may take place during hydrocooling of loose fruit.

[336d] Anon., *Better Fruit, 37,* 5 (1942).

CHAPTER IX

STORAGE OF APPLES IN FRESH STATE

A. Introduction

Apples are held in various types of storages to provide a regulated supply of this fruit to the market throughout the winter and the spring. Storages serve the function of preserving this rather perishable commodity from a time of plenty to a time of relative scarcity. Whether or not the apple grower will get a high enough price for his fruit to realize a profit after paying storage costs depends upon several factors. One of the most important of these is the quantity of apples stored by other growers. After seasons of high production storage holdings tend to be large and returns are likely to be small. Another important consideration is the buying power of the public or the general economic conditions during the storage period. There have been years when growers obtained more for their apples during the harvesting season than they did after a rather long storage period. Generally speaking, however, the grower can expect to gain some advantage by not selling all of his fruit during the harvest season. Only occasionally does it pay a grower to store apples lower in grade than U. S. No. 1, particularly if the storage season is expected to be more than a few months in length. Only apples of good marketable size are likely to justify the expense of storage. Small off-grade apples might better be placed in by-product channels rather than stored for fresh fruit sale in the winter or spring.

1. COMMON STORAGE

There are a number of techniques used in common storage. Common storage refers to holding apples without refrigeration, depending upon outside air to do the cooling. Insulation is necessary to prevent freezing during the winter months.

Covered Heaps of Fruit. Frequently processors of apples merely store their fruit in huge piles near their plants. The fruits are covered with about one foot of straw to prevent freezing. Apples

have often been kept this way satisfactorily until December first or somewhat later. The straw does not provide sufficient insulation to prevent some freezing when the temperature drops very low. It is partly for this reason that they cannot be kept very long in this fashion. Another reason is that there is no way of ventilating the fruit with cool air during the nights of October and November. Still another reason is that the apples are not cooled very rapidly, partly because of the lack of ventilation with cold air and partly because of the heat of respiration involved in such huge stacks of fruit.

Air-cooled or Ventilated Storages. More frequently apples held in common storage are placed in insulated buildings.[337 342] During the fall months the insulated structure is cooled by introducing air during the night and closing the storage during the day. In winter, of course, the insulation protects the fruit against outside freezing temperatures. The outside air is introduced for cooling through suitable ports. The air may be circulated by gravity or it may be forced through the storage by fans. Various types of air-cooled storages are discussed below.

The main limitation of any of these types of common storages is that it is not possible to cool the fruit rapidly enough in the fall. All too frequently the night temperatures during the harvesting season and for some little time thereafter are not low enough to accomplish very much cooling. Of course, when freezing temperatures of the winter prevail it is possible to keep the storage cold enough if it is properly designed.

The design of all common storages is based on the principle that a given volume of warm air is lighter than an equal volume of cold air, and air movement results from the pressure difference. Air in contact with the fruit becomes warmed and is then displaced by cooler, heavier air which forces the warmed air up out of the storage. Gravity ventilation is the process taking place as a result of the current of air started by the warming effect of the fruit. Wind pressure (originating from temperature differences in the open) also causes air to move through a storage by creating a pressure on the windward and a suc-

[337] J. R. Magness, (*Mimeo*) *Office of Hort. U. S. D. A.*, 1927.
[338] R. D. Anthony and F. G. Hechler, *Penn. Agr. Expt. Sta. Bull.*, 241, 1929.
[339] R. E. Marshall, *Mich. Agr. Expt. Sta. Circ.*, 143, 1939.
[340] C. E. Baker, *Indiana Agr. Expt. Sta. Circ.*, 154, 1928.
[341] I. M. Marble and R. D. Anthony, *Penn. Agr. Expt. Sta. Bull.*, 191, 1925.
[342] H. J. Ramsey and S. J. Dennis, *U. S. D. A. Farmers' Bull.*, 852, 1917.

tion on the leeward side of the building. The movement of air through the storage by the force of the wind alone is dependent upon the direction and velocity of the wind as well as on the shape, size, and position of the building and openings in the building. In some storages there is forced ventilation by means of fans or blowers. When thermostats are used on both outside and inside air in the common storage, fan operation can be automatic.[342a]

Comin has outlined the systems used in ventilating common storages as follows:[343]

"Using natural gravity ventilation are the: (*a*) Cope system, (*b*) Magness system, and (*c*) a combination of the Cope and Magness systems. Using forced ventilation are the: (*a*) power fan system, (*b*)cowl-induced ventilation system, and (*c*) wind pressure systems. In the Cope system cold air enters the building through openings distributed around its walls at the floor level; this air by virtue of its great weight replaces warmer air which is forced out through a flue in the ceiling. This general system is probably most commonly used today. In the Magness system the cold air is allowed to enter the room through openings at about the height of the top crates of fruit. The warm air is forced out through the same openings. In a combination of the Cope and Magness systems there are openings at both the floor level and near the top of the room as well as an outlet flue at the ceiling.

"Intake and outlet openings must be adequate for proper movement of sufficient volumes of air. It has been found that an average of 50 cubic feet of air under fall conditions is required to cool a bushel of apples 1°F. when there is a temperature difference between air and fruit of 4° to 5°F.[839] Other studies have indicated that from 75 to 225 cubic feet per minute per bushel would be required for each bushel for a 5°F.. temperature difference.[337,344]"

Comin[343] has also described the types of common storage in some detail. Some storages are below ground, basement, or bank storages. He points out that the earth when in contact with any portion of a storage exerts a powerful effect on the air temperature of the storage as follows:

"This effect is in direct proportion to the surface area in contact with the earth and is lessened by the use of insulation. This may be an advantage or a disadvantage depending upon the temperature desired in the storage. During the summer and early fall the temperature of the earth is lower than that of the air and the soil absorbs heat and cools the storage. During the winter the soil is warmer than the air and gives up heat to the storage air. In the fall the under-

[342a] J. H. L. Truscott, W. W. Franklin, and J. Gilliat, *Sci. Agr., 29,* 497 (1949).
[343] D. Comin, *Ohio Agr. Expt. Sta. Bull.,* 573, 1936.
[344] A. M. Goodman, *Cornell Univ. Extension Bull.,* 453, 1940.

ground storage undoubtedly maintains the fruit at a lower average and more constant temperature than is found in the above-ground type. This fact cannot be overlooked and explains why many underground storages seem to keep fruit as well as the above-ground structures. The damage to the fruit wrought by high fluctuating temperatures during the early storage period is considerable and more difficult to overcome with an above-ground building. On the other hand, during the major portion of the storage period it is somewhat more difficult to maintain as low temperatures in the below-ground as in the above-ground types. Air temperatures of 36° to 40°F. (2–4°C.) are automatically maintained in underground storages."

Most common storages are above ground.

"This type seems to be preferred for apples. Frequently, because of an uneven grade, the earth may be banked against the walls a foot or more above the floor level. However, the walls are insulated to the floor and the storage is considered to be above ground. Many such buildings also have the floor insulated with a foot or so of cinders beneath the concrete surface. Heat evolved from an earth floor increases the difficulty of maintaining a low temperature during the early storage period. Many growers are convinced that the advantages of an earth floor may be artificially supplied by ample insulation to prevent winter freezing and the adding of water by hose or other method to maintain a high humidity. The advantages of a concrete floor upon which to handle fruit are unquestioned, and the recent trend towards such floors in common storages suggests they are proving successful. An insulated floor of some type is essential in a refrigerated storage.

"Adapting to storage use such buildings as are available on the farm is a common procedure. The cost is low so that the storage is almost certain to prove a profitable investment for even the grower with a small acreage. It is not difficult to provide storage in this manner and such facilities will often keep fruit as well as the more costly structures."[343]

Cooling of the common storage is sometimes supplemented by the use of ice,[345] since the greatest damage to fruit in common storage is likely to occur during the early part of the storage season when outside temperatures are high. By use of ice it has been possible to reduce storage temperatures by 10° to 16°F. below the temperature of a similar room without ice. When cracked ice and salt were used it was possible to lower the temperature by 18° to 22°F. during September and October. Even so, the actual storage temperature was never below 40° and averaged 45° during those months. The seasonal cost of icing and operating the iced room varied from 16 to 26.6 cents per bushel with an average of 20.8 cents per bushel for 6 years. This

[345] C. E. Baker, *Purdue Univ. Agr. Expt. Sta. Bull.*, 379, 1933.

is a rather high cost. Artificial refrigeration would not be that high. The economy of ice in cooling storage rooms is hence doubtful and would depend upon the price of ice and the rise in market price of the fruit as the season advanced.

2. REFRIGERATED STORAGE

Because of the limitations of common storage for apples, refrigerated storages permit longer storage life for this fruit. Refrigerated storages may be located on the farm or they may be refrigerated warehouses in a centrally located place in the growing area or they may be located in large cities.

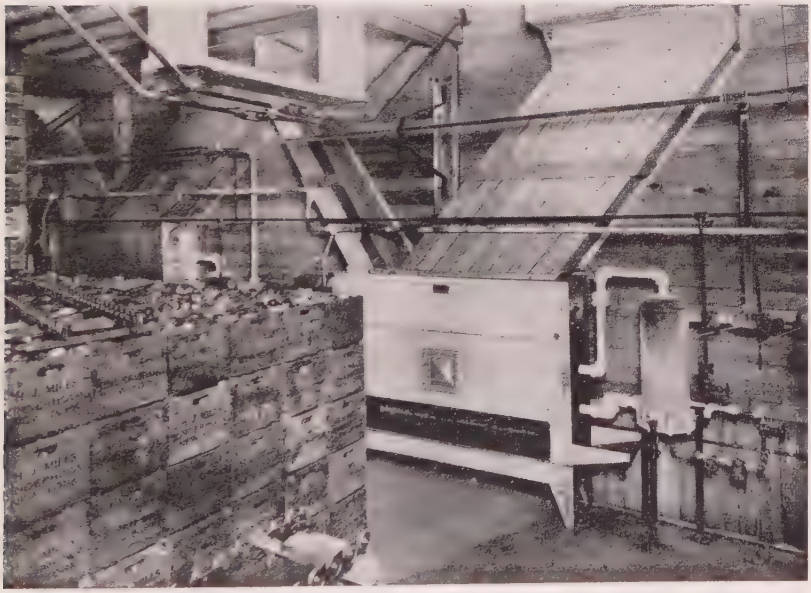


Fig. 46. Interior of refrigerated farm apple storage room showing cold diffusers (courtesy Niagara Blower Company, Buffalo, N. Y.).

Refrigeration on Farm Versus Central Warehouses. One of the most striking developments in recent years in many parts of the United States has been the rapid growth of refrigeration on the farm. There are now (1950) several hundred refrigerated farm storages throughout New York and New England. A similar increase in

number has been noted in the Middle West. In other areas such as in California and the Pacific Northwest there has not been any increase in farm storages probably because of marketing practices.

The rapid growth of refrigeration on the farm can be attributed to several factors. One has been the striking development in refrigeration equipment. The adaptation of modern air-conditioning equipment with its efficiency and relative cheapness has stimulated many apple growers to build their own storages. Another reason has undoubtedly been the increase in the amount of fruit moved by truck. Much of the fruit handled in New York and New England is moved by trucks which come right to the doors of the farm storage. This does not mean that there is still no place for the central refrigerated warehouse. Each grower or fruit-growing community must decide which type it wants on the basis of its own needs. To make a judgment on which type will best serve its requirements, the advantages and disadvantages of each type of storage should first be examined (Fig. 46).

Advantages of Farm Storage. (*A*) Refrigeration on the farm is usually cheaper[346,347] because the building is usually not as expensively constructed as the central storage; building costs are usually lower. Overhead costs are usually lower in farm storage. Men in the commercial warehouse business will often refute this point of comparative costs, but all the cost account records kept in New York State show that it is relatively cheaper for the fruit grower to store the fruit in his own storage.

(*B*) The grower has closer supervision over his own fruit. While he may keep close supervision of his own fruit in a central warehouse, it is not frequently enough practiced by fruit growers. For example, when apples begin to show scald they should be moved quickly into market. If the grower is looking at his fruit every few days he may note this type of change in fruit condition and move his fruit quickly. Too much fruit has deteriorated in large warehouses for lack of close inspection.

(*C*) The grower usually has closer contact with his buyers. This assumes that buyers are coming to his storage doors and are trucking away the fruit.

(*D*) The grower can store his fruit field run if he so desires. Many farm storage operators list as one of the main advantages of their storages the fact that they can level out their labor of packing by storing much of the fruit just as it is picked and then packing it during the postharvest season.

Disadvantages of Farm Storage. (*A*) The farmer cannot always supervise the equipment as well as a trained engineer at the central warehouse. This difficulty is not always an important one with the modern equipment with automatic controls that is available.

[346] D. Comin, *Ohio Agr. Expt. Sta. Bull.*, 632, 1942.
[347] E. L. Arnold, *Cornell Univ. Agr. Expt. Sta. Bull.*, 724, 1940.

(*B*) The initial capital outlay that is required for a farm storage is often too large for the fruit grower as an individual.

Advantages of Central Refrigerated Warehouses. (*A*) Apples are assembled in large quantities. This is often a convenience for large buyers.

(*B*) It is usually more convenient for a central warehouse to have railroad facilities than many individual storages. Where trucking is not a large factor, railroad facilities are extremely important.

(*C*) There is an initial pooling of capital which makes it less of a hardship for individual growers.

(*D*) The large warehouse often has a source of income from the storage of other products during the "off season." This opportunity is often not available to or not wanted by the small operator who has farming operations to worry about during the summer months.

The disadvantages of a central warehouse are indicated under the advantages of the farm storage.

Whether a given community decides upon individual farm stor-

TABLE 27. Estimated Cost of Operating a Cold Storage on the Farm[a]
Itemized Costs Based on a Storage of 10,000-Bushel Capacity
Total Cost: Refrigeration $2500; Building $7500[343]

Items of annual cost	Per cent of the total investment for		Cost, dollars		
	Refrigeration	Building	Refrigeration	Building	Total
Depreciation on refrigeration equipment and building	7.5	5	187.50	375.00	562.50
Interest on depreciation refrigerating equipment and building	5	5	125.00	375.00	500.00
Tax and insurance	1.5	1.5	37.50	112.50	150.00
Maintenance	3	1	75.00	75.00	150.00
Power, 1 kilowatt per bushel at 3 cents	—	—	300.00	..	300.00
Total annual cost	—	—	725.00	937.50	1662.50
Total annual cost per bushel	—	—	0.07	0.09	0.16

[a] Figures on percentage of the total investment for equipment and for building are those suggested by companies installing farm refrigeration systems.

ages or a central warehouse will depend upon the foregoing factors as well as the normal marketing procedures.

Cold Storage Costs. Very little information is available on cold storage costs in large commercial warehouses. Such information is hard to obtain because such houses usually store mixed products even in the same room and use the room for other products besides apples during the off season for this fruit. While storage charges vary some-

what with conditions, typical storage charges for apples are 10 cents for the first month of storage per bushel and 5 cents for every additional month. If the apples are kept for a 6-month season the season's cost is 25 cents. These figures are based on 1930–1950 costs.

Comin has summarized farm storage costs for Ohio conditions as shown in Table 27.[346]

In a New York study it was calculated that the cost per bushel in 23 different storages, using 2.5% for insurance, 5% for depreciation, 5% for interest, 3% for repairs, 3.6 cents per bushel for power, and 1 cent per bushel for handling costs, ranged between 7 and 30 cents per bushel per season with an average of 16 cents.[347]

The cost of storing apples in farm storages is considerably lower than in commercial warehouses. The cost per bushel in commercial warehouses ranges between 22 and 25 cents per bushel for the storage season. Commercial warehouses have higher costs due to higher overhead and the necessity of showing some profit.[346]

Equipment for Cooling in Refrigerated Apple Storages. There are many variations in the equipment used in cooling apple storages but there are some features common to all. In the storage room is found an *evaporator* of some type. In the evaporator the liquid refrigerant expands and absorbs heat. The evaporator is a heat exchanger in which the heat from the storage room is extracted and transferred to the refrigerant. The evaporator may consist of pipe coils which depend upon convection currents to circulate the air around them. The evaporator may be composed of a cabinet containing coils, finned coils, or plates, through which air is forced. This type of unit is usually called a cold diffuser. Sometimes the cooling surfaces are dry in these diffusers and sometimes they are sprayed with calcium or sodium chloride brine to keep them free from frost. Outside the room a *compressor* is necessary. The refrigerant in the gaseous form comes to the compressor from the evaporator and is compressed. During compression the temperature of the refrigerant is raised. The refrigerant is then delivered to a *condenser* which is cooled by either air or water. In the condenser there is a heat exchange from the refrigerant (now warm) to the cooling medium. After being cooled the compressed refrigerant (such as ammonia or Freon 12) changes to the liquid form. The liquid refrigerant is now piped into the evaporator. It is released into the evaporator through an *expansion valve*. Beyond the expansion valve the pressure in the system is lower and the liquid

refrigerant expands as described previously to absorb heat. Of course, there are many accessories required for the proper functioning of these parts but this describes the main parts of a refrigerating system.

A classification of the various types of equipment used in cooling apple storages appears below:

I. Direct expansion
   A. Bare pipe coils suspended from the ceiling, walls, or center supporting posts. Storage air moves over the coils by gravity alone or aided by fans.
   B. Special coils with fins suspended from the ceiling. Fans may be used.
   C. Specially compacted coils, usually with fins, installed in a cabinet equipped with blower fans. Such units may be ceiling or floor mounted. Several smaller finned coils with propeller-type fans attached may be suspended from the ceiling.
      1. Blower units may be equipped with brine spray nozzles to allow low temperatures to be maintained without frosting of the coils.
      2. Brine may be cooled, then sprayed into chamber through which storage air is drawn.

II. Indirect systems
   Brine is cooled in a small tank unit with cooling coil; the cooled brine is then circulated through pipes in the storage room.[346]

3. CONTROLLED ATMOSPHERE STORAGE

Apples can ordinarily be held satisfactorily for rather long periods in ordinary cold storage. There are certain instances, however, where cold storage alone has not proved entirely adequate. For example, McIntosh apples cannot be held in ordinary cold storage with full assurance that they will be of prime eating quality after February or March at the latest. McIntosh frequently develops a cold storage disorder known as brown core, when held for extended periods in ordinary cold storage.

Controlled atmosphere storage would seem to be a logical supplement to cold storage with this leading variety of New York and New England. The principles of controlled atmosphere storage were originally developed by Kidd and West in England.[347a]

What Is Controlled Atmosphere Storage? Fruits carry on respiration, a process which is characteristic of all living things. In respiration, sugars are oxidized, or burned, in the presence of oxygen:

[347a] F. Kidd and C. West, *Food Inv. Board*, Leaflet 9, 1935.

carbon dioxide, water vapor, and heat are produced as a result of the process. The more rapid the respiration, the more quickly the fruits will deteriorate. The rate of respiration may be reduced by several means. The first means is to lower the temperature. This is the fundamental principle of cold storage. The second means is to reduce the amount

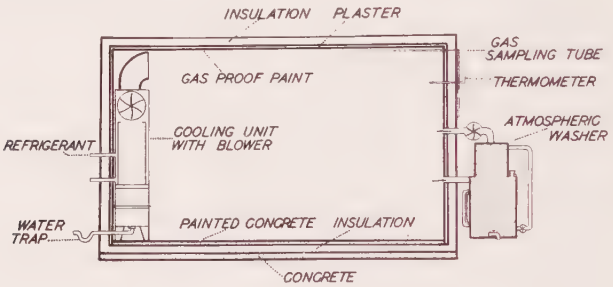


Fig. 47. Diagram of section of controlled atmosphere room for apples. Such rooms are usually made gastight with sheet-metal lining instead of painted concrete, however.

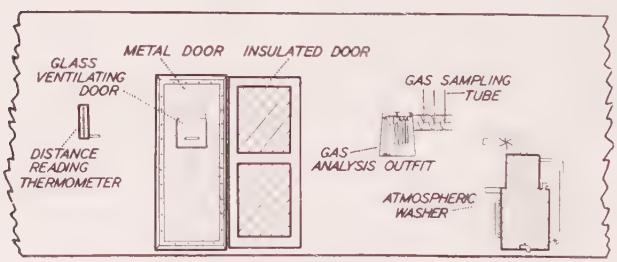


Fig. 48. Diagram of exterior of controlled atmosphere storage chamber for apples.

of oxygen available to the fruit, since oxygen is required in respiration. The third is to increase the normal amount of carbon dioxide around the fruit. Accumulations of carbon dioxide slow down the chemical reactions involved in respiration. A combination of all three of these principles is involved in controlled atmosphere storage (Figs. 47 and 48 above).

In a gastight room that has just been filled with apples, the atmosphere in the room is ordinary air. Air is composed of about 78%

nitrogen, 21% oxygen, 0.03% carbon dioxide, and small percentages of other inert gases. After sealing the room the constituents of the atmosphere are certain to change in this gastight room. Because of respiration the oxygen is consumed and finally completely exhausted unless the storage operator makes provision for supplying some fresh air. When the normal percentage of oxygen is completely gone, the quantity of carbon dioxide present is approximately 21%, since it is produced in volumes about equal to those of oxygen consumed. If this

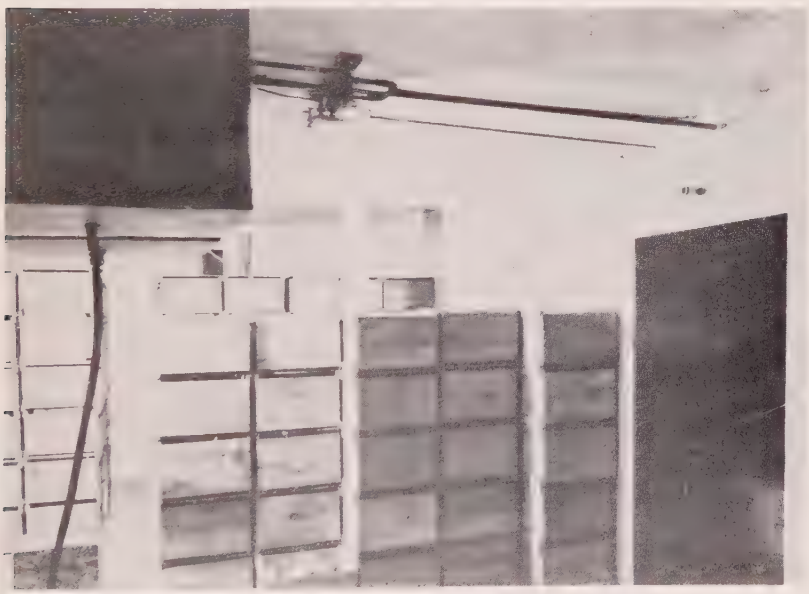


Fig. 49. Interior of sheet-metal lined controlled atmosphere apple storage. Cold diffuser in upper left.

were allowed to proceed much farther, the fruit would become alcoholic in a very short time. But if, when the percentage of oxygen reached is 11%, it is maintained at that figure by introducing small amounts of fresh air as required, the carbon dioxide would now be 10%. In fact, the percentage of carbon dioxide in this type of storage can be estimated by subtracting the oxygen figure from 21%. The remainder of this atmosphere of 10% carbon dioxide and 11% oxygen is always nitrogen. This atmosphere of 10% carbon dioxide and 11%

oxygen, with a temperature of 40°F. (4°C.), is the one most commonly used in England. When the carbon dioxide indicator shows more than 10% carbon dioxide, the room is ventilated as required to maintain that figure. No attention is paid to the nitrogen fraction.

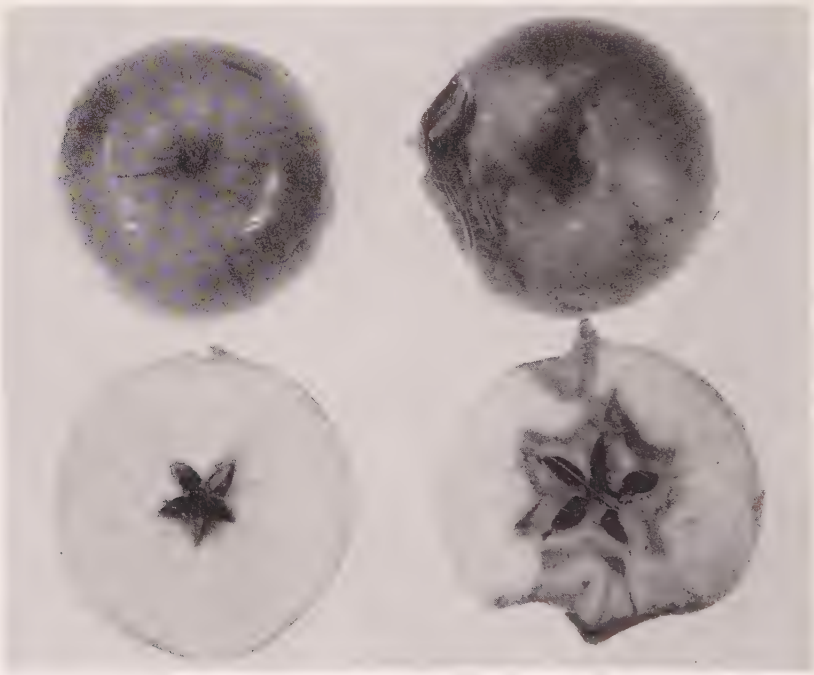


Fig. 50. McIntosh apples removed from storage March 1, 1941, and then held at room temperature in a high relative humidity for four weeks: right, out of cold storage in 32°F. (0°C.) air—note brown core; left, out of 5% carbon dioxide and 2% oxygen at 40°F. (4°C.).

Suppose a certain variety responds best to a very low oxygen atmosphere, such as 2%, and 5% carbon dioxide. First, respiration will lower the oxygen figure from the normal of 21% within a month or slightly less in a gastight room filled with fruit. When the oxygen figure falls below this amount, small quantities of fresh air are introduced as required. The carbon dioxide cannot be controlled by ventilation in this instance because small introductions of air sufficient to control the carbon dioxide would raise the oxygen percentage higher than

desired. For this reason when the carbon dioxide percentage exceeds 5% the storage atmosphere is passed through an atmospheric washer containing a solution of sodium hydroxide or lye, which removes carbon dioxide. This washing is continued until the carbon dioxide is back to 5%. Control of the atmosphere can be obtained by mere ventilation only when the summation of the carbon dioxide and oxygen percentages equals 21%.

Advantages of Controlled Atmosphere Storage. The storage life of certain varieties of apples is markedly increased by use of the proper atmosphere and temperature. Several months can be added to

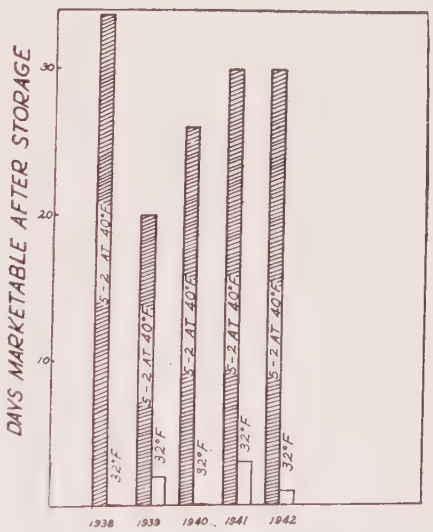


Fig. 51. Comparison of period of marketability of McIntosh apples following removal from storage in early May with ordinary cold storage at 32°F. (0°C.) air and controlled atmosphere storage (5% CO_2–2% O_2 at 40°F. (4°C.)).

the normal storage life of McIntosh, which is normally past its prime condition in ordinary cold storage at 32°F. (0°C.) in air by March.

A marked residual effect is noted frequently as a result of this treatment. For example, McIntosh apples removed from controlled atmosphere in March or April remain marketable for long periods of time at room temperatures. In other words, not only do apples have a longer storage life, but they remain marketable for much longer periods of time on the market place than do cold storage apples.[348]

[348] R. M. Smock and A. Van Doren, *Cornell Univ. Agr. Expt. Sta. Bull.*, 762, 1941.

Several varieties of apples are subject to internal disorders such as brown core, or core flush, and internal browning when stored at temperatures as low as 32°F. (0°C.) in cold storage. When stored in controlled atmospheres of the proper proportions of carbon dioxide and oxygen at a temperature of 40°F. (4°C.) these troubles can be avoided in McIntosh.[348,349] See Figure 50, page 204.

Mold growth is not quite as rapid in controlled atmosphere storage as in ordinary air storage. However, if the humidity is kept at 90–95% some mold growth may appear on the boxes and walls. Mice and rats cannot survive in controlled atmosphere storage, and hence there is no damage to the fruit from this cause.

Disadvantages of Controlled Atmosphere Storage. Because of the danger of suffocation and also because of loss of the required atmosphere in the chamber, the storage operator cannot enter the storage room until the room is unsealed. Fruit must be inspected through a window in the door. By using an oxygen mask the operator could go into the room, but opening of the door causes a considerable loss of the atmosphere.

This method of storage is ordinarily used for fruit that is to be marketed after cold storage fruit would be past its prime. This means that the storage operator must operate both cold storage and controlled atmosphere rooms if he is to sell apples from harvest time through June or later. When a variety such as McIntosh is stored in controlled atmospheres, the room can be opened in March or April and ordinary cold storage used in the room thereafter during the marketing period.

Fruit of markedly different degrees of maturity, whether of the same variety or different varieties, cannot be stored together in the same room.

Judging from the experimental work done to date on the subject, different varieties cannot be stored in the same room. Some varieties at least tend to ripen or cause scald in other varieties when they are stored in the same chamber. For example, Wealthy developed scald when stored with McIntosh.[350]

The rooms must be gastight. If they are not, the venture is likely to fail.

[349] W. R. Phillips, *Sci. Agr., 19,* 66 (1938).
[350] R. M. Smock and F. W. Southwick, *Cornell Univ. Agr. Expt. Sta. Bull.,* 813, 1945.

The hazard of storage scald is increased in controlled atmosphere storage. Scald is caused by accumulation of certain volatiles produced by the fruit itself. In a gastight room there is little flushing away of these gases, and hence scald tends to be accentuated. McIntosh, which is ordinarily not classed as a scald-susceptible variety, will scald in controlled atmosphere storage unless precautions are taken.[350]

It is more expensive than ordinary cold storage. It costs about 10 cents per bushel more for each storage season.[348]

Varietal Response to Controlled Atmosphere Storage. The variety which responded most markedly to controlled atmosphere treatment in Cornell studies was McIntosh. The storage life of McIntosh can be doubled in controlled atmospheres, as compared with ordinary cold storage in air at 32°F. Brown core was entirely avoided by use of controlled atmospheres at 40°F.

Northwestern Greening, Twenty Ounce, Golden Delicious, Rome Beauty, Macoun, Kendall, Delicious, and Northern Spy responded fairly well. Scald may cause trouble in the first four, particularly in some years. Since danger of mealiness development has been reported with Delicious,[351] further trials probably should be made with this variety.

Jonathan has not given good results in New York trials but it has in Iowa experiments.[352] Jonathan was susceptible to a type of internal browning in controlled atmosphere storage in New York, but Jonathan spot was avoided with this type of storage. Yellow Newtown has shown promising results in California.[353]

Cortland responded well from the standpoint of firmness and crispness but was extremely susceptible to scald one year in a two-season experiment. Rhode Island Greening seemed very susceptible to brown core in an atmosphere with carbon dioxide. Baldwin and Wealthy were seriously affected by brown core in the atmosphere employed in a one-year test.

4. STOWING THE FRUIT

The containers used in storage are widely divergent in type. If the apples are packed after storage, wooden or slatted wooden crates are used. The disadvantage of the slatted crate is that it may cut the

[351] D. V. Fisher, *Proc. Am. Soc. Hort. Sci., 37,* 459 (1940).
[352] H. H. Plagge, *Refrig. Eng., 43,* 215 (1942).
[353] F. W. Allen and L. R. McKinnon, *Proc. Am. Soc. Hort. Sci., 32,* 146 (1935).

fruit. If the apples are packed before storage, standard market containers are used. Sometimes when apples are placed in storage for processing at a later date they are stored in bulk. One layer of apples is placed across the floor of the room in boxes and then the apples are piled up in bulk on top of the boxes. Of course, this results in slower cooling and considerably more bruising and stem punctures.

In stacking the crates or boxes some space should be allowed between walls, ceiling, and floor to allow ample air circulation around the containers and throughout the whole room. The exact amount of space varies from 0.50 foot to 1 foot or more, depending upon whether circulation is by gravity or is forced. If the packages are of the extremely tight type, it is of the utmost importance that some spaces be left between the layers and tiers of fruit. It is common practice where tight box packages are used to use 0.5-inch wooden strips between every layer of boxes. Where rather open containers are used such as field crates or New England apple boxes it may not be so necessary to use such "dunnage" in stowing the fruit. However, some operators have found it to advantage with even this type of package to allow a 1-inch air space around every 4 boxes, that is, a square of 4 boxes is piled up so that every box has 2 sides exposed to a 1-inch air space. It is a common practice to use 0.5-inch strips of wood under the first layer of boxes so that the fruit is up off the floor and hence air can get back to the cooling surfaces, especially in coil-cooled rooms.

While it is important to have sufficient space at the floor, at the ceiling, and at the walls it is occasionally overdone. Spaces too large and poorly arranged may do more harm than good. Misplaced aisles or other large spaces in the storage may result in short-circuiting of the cooling air.

B. Factors Affecting Storage Life of Apples

Two very important factors that affect the length of keeping of apples in the storage have already been discussed, namely, the *maturity* of the fruit and the *care with which it is handled*.

1. IMMEDIATE AND DELAYED STORAGE

Ordinarily apples should be placed in storage as soon as possible after picking. Any delay either in the orchard or on the packing-house

floor during periods of high temperatures is certain to shorten the storage life of the fruit.

Delay between the time of picking and the time of storage is known to increase such storage troubles as bitter pit and scald on susceptible varieties. In two years of work at Cornell with Northern Spy a delay of one week before storage has doubled the amount of bitter pit. Shriveling of the skin is accentuated when apples are allowed to remain exposed to high temperatures and rather low relative humidity after picking.

The New Hampshire Agricultural Experiment Station recommends that if brown core of McIntosh is to be prevented, a five-day delay before storage should be practiced.[354] It is recognized that such fruit should probably be sold before Christmas even though held in cold storage. A suggested additional advantage of this period of delay is the better eating quality. Investigations at Cornell indicate that the determining factors in the success of delayed storage for the purpose of a reduced amount of brown core and better quality are the temperature and relative humidity existing during the period of delay. In one year the temperature during the period of experimental delay was as high as 80°F. on the packing-house floor. Because of variations in temperature and humidity, uniformly successful results cannot always be guaranteed. As much as 40% of brown core has been observed in McIntosh after the period of storage at 32°F. following a five-day delay prior to storage.

It has been estimated that each day of delay before storage takes approximately one week off the storage life of McIntosh at 32°F. When practicing delayed storage, one must be aware of the sacrifice in the length of storage life of the fruit as well as any possible advantages that may accrue.

2. TEMPERATURE

As has been pointed out, the temperature at which apples are stored is of utmost importance. Temperature affects the ripening rate of apples, the moisture loss from fruit, and the growth of molds and decay organisms in the storage chamber.

Freezing Point of Apples. From the discussion of the effect of temperature on the respiration rate of apples it may be seen that the lower the temperature, the slower this process proceeds. The

[354] E. J. Rasmussen, *New Hampshire Agr. Expt. Sta. Tech. Bull.*, 67, 1937.

question arises then as to how low the temperature can be held without injury to the fruit. The apple is 85% water and the freezing point of water is 32°F. (0°C.). The dissolved sugars and other materials in the juice of the apple lower the freezing point somewhat below that of water. The exact freezing point depends upon the variety but usually is between 27° (—2.7°C.) and 28°F. (—2.2°C.).[355]

Recommended Temperatures for Storage. From the indicated freezing point of apple tissue, it may be seen that storage at 30°F. (—1°C.) would not result in freezing. There are several reasons why a temperature this low is not commonly recommended although it is used in some apple storages. This temperature is a little too close to the actual freezing point of the fruit; a drop of 3° due to some fault in the refrigeration system might cause considerable damage to the fruit. Also, in varieties such as McIntosh storage at 30°F. (—1°C.) is not conducive to the development of best eating quality. It also results in excessive development of low-temperature disorders, such as core browning or brown core, soft scald, soggy breakdown, and internal browning, in susceptible varieties. Therefore, the most commonly used and recommended temperature for storage of apples is 32°F. (0°C.). Some controversy, however, exists as to the proper temperature. In the Middle West a temperature of 36°F. (2°C.) is recommended, but many of their varieties are subject to low-temperature troubles such as soft scald and soggy breakdown. It is argued further that better quality develops in fruit held at a higher temperature. It has been demonstrated at Cornell that in the late part of the storage season brown core of McIntosh is more severe at 32°F. (0°C.) than at 36°F. (2°C.). The following facts must be kept in mind in deciding at what temperature to store apples.

(*1*) How long are the apples to be kept? If certain varieties are to be removed from storage by February, it is possible that a saving in refrigeration can be effected without any great loss by storing at 36° to 40°F. instead of 32°F.

(*2*) Is the variety susceptible to low-temperature troubles such as soft scald, brown core, or soggy breakdown? The value accruing to a variety such as McIntosh stored at 32°F. and kept until February or slightly after might sometimes offset the waste from brown core.

(*3*) Is the variety susceptible to troubles such as scald and bitter pit? These troubles develop more slowly at 32°F. than at higher temperatures.

(*4*) Is the apple maggot a serious trouble? If so, a temperature of 32°F.

[355] D. B. Carrick, *Cornell Univ. Agr. Expt. Bull. Mem.*, 81, 1924.

is needed for a period of one month to inactivate any larvae that may be in the fruit. This is especially pertinent with fruit to be exported.

(5) How difficult is the attainment of a high relative humidity with the particular refrigeration equipment being employed? It is much easier to maintain a relative humidity of 90% at a temperature of 33° (0.6°C.) to 34°F. (1.1°C.) in the storage than at 32°F. (0°C.). Again it must be realized that the higher temperature will result in slightly more rapid softening. In certain instances, freedom from shriveling may be more important than this difference in softening.

Thus it can be seen that one cannot specifically recommend a storage temperature unless the requirements of both the variety and possibly certain marketing plans of the operator are known. In New York, when varieties such as Northern Spy, Rhode Island Greening, and McIntosh are being stored in a single room for long-time storage, the most common storage temperature is 32°F. (0°C.).

Effect of Rapid Drops in Temperature. The opinion is often expressed that apples should be cooled slowly to prevent possible "shock" to the fruit. As far as is known there are no ill effects from rapid cooling. The more rapidly the temperature of the fruit itself can be reduced to the storage-room temperature the better, because respiration and fungus growth are checked. In precooling apples rapid air cooling with subfreezing temperature is used until the temperature of the apples approaches 32 F. (0 C.). No harmful effects have ever been noted from this practice. One of the advantages frequently given for a "blower" type of cooler, as compared with a coil type of cooler with gravity circulation of air, is that field heat is more rapidly removed. It has been shown that cooling of warm fruit was almost six times as rapid in a blower-cooled room than in a coil-cooled room.[356] All experiments to date have shown that the more quickly field heat could be removed the more advantageous it was to the fruit.

Effect of Temperature Variations. A number of storage operators have expressed the belief that temperature fluctuations were harmful to the fruit. It is true that any great temperature rise for an extended period could speed up the rate of fruit ripening. Small fluctuations of one or two degrees seem to have little effect as long as the average temperature remains at 32 F. (0 C.) or any other desired temperature. Even a rise of 5 or 10 F. for a short period in the room, once it is cooled, might have no serious results since the

[356] E. J. Rasmussen, *Proc. Am. Soc. Hort. Sci., 28,* 568 (1931).

apple is 85% water and its specific heat is about 0.9 and it warms very slowly.

A wide fluctuation or variation in temperature from one part of the storage to the other must be prevented. It has been shown that air movement as supplied in a blower type of storage is more conducive to even temperatures throughout the room than is a coil type. Well-placed fans in a coil type of storage can readily eliminate cold-air pockets or prevent stratification of cold layers near the floor. Apples placed too close to coils at a near-zero temperature may freeze. Some spacing of the boxes away from the coils or the use of fans may help to prevent this hazard.

Use of Different Temperatures. Since full development of aroma and quality is somewhat hampered in a variety when stored continuously at 32°F. (0°C.), a modification of this practice is sometimes followed. Experiments in Massachusetts[357] have indicated that when McIntosh was not to be held after January, slightly better quality could be had by storing for about two weeks at 45°F. (7°C.) and then by the end of the third week gradually lowering the temperature at 32°F. (0°C.). Ripening, of course, proceeded rapidly at the higher temperatures but quality was better than in fruits held continuously at 32°F. (0°C.). This is in some measure a modification of "delayed storage" when practiced to develop fuller quality. Any of these modifications may be practiced with justification if the operator realizes the sacrifice in length of keeping that they entail. The standard procedure with most varieties, however, has been continuous operation at the chosen temperature.

3. RELATIVE HUMIDITY

Importance of Relative Humidity. As has already been pointed out, the relative humidity in the apple storage should ideally be close to 100% if all shriveling and weight loss is to be prevented. It is difficult to maintain high relative humidities from an engineering standpoint, however. The very cold cooling surfaces keep condensing water vapor from the air and possibly freezing it, and thus reduce the relative humidity. A second difficulty is that molds grow rapidly even at 32°F. (0°C.) in the higher relative humidities. With apples the most common practice is to use a relative humidity of from 80 to 85%. This is a compromise figure between that which may result in shriveling

[357] C. I Gunness, W. R. Cole, and O. C. Roberts, *Mass. Agr. Expt. Bull.*, 360, 1939.

and that which may cause excessive mold growth. A number of apple storages are operating with 90% relative humidity, however. Slight mold growths on the surface of the boxes and walls of the rooms are held to be less of a disadvantage than is fruit shriveling.

With considerable air movement in the storage room there is less likely to be local condensation at high relative humidities. Since surface-growing molds apparently do not flourish except in the presence of a film of moisture, air movement is of some advantage. Because of this, where there is considerable air movement in the storage, humidities as high as 90 to 95% sometimes can be maintained without excessive mold growth. When temperatures higher than 32°F. (0°C.) are used, one should employ more than from 80 to 85% relative humidity because water is lost more rapidly as the temperature rises even at the same relative humidity. In other words, at high temperatures the drying power of the air is greater than at lower temperatures.

Maintenance of Relative Humidity. The maintenance of relative humidity is essentially a problem of engineering, but here are a few suggestions. If the differential between the temperature of the refrigerant and that of the room is small, maintenance of the proper relative humidity is not as difficult as it would otherwise be. With the modern air-conditioning machinery that is used in cooling some storages, if the air leaving the conditioner is saturated with moisture at 25°F. (−4°C.) and the room is at 35°F. (2°C.), the relative humidity in the room will be about 64%. If the air leaving the conditioner is saturated at 30°F. (−1°C.) instead of 25°F. (−4°C.), the relative humidity in the room at 35°F. (2°C.) will be 80%.

Besides the refrigerant temperature there is another factor which may well determine the relative humidity of the storage atmosphere, that is, the dryness of the wooden containers. Studies[358,359] have shown that wooden fruit containers can absorb considerable quantities of water. A heavy field crate weighing about 10 pounds if air dried during the summer period has been found to absorb about 1 pound of water during the cold storage period. A lighter box called the New England apple box has been found to absorb about 0.5 pound of water. Of course, the amount absorbed by the wood depends upon how dry the wood is when the boxes are placed in storage. This effect of the

[358] S. A. Pieniazek, *Ice and Refrig., 102,* 43 (1942).

[359] D. Comin, W. Junnila, and C. W. Ellenwood, *Ohio Agr. Expt. Sta. Bi-monthly Bull., 29,* 230 (1944).

wood is most profound during the early part of the storage season until the wood comes to equilibrium with the water vapor content of the atmosphere. Naturally, the main source of water vapor in the room is the fruit itself and this means that water leaves the fruit and goes to the wooden boxes. This fact emphasizes the necessity of keeping the relative humidity high at all times.

Water can be atomized into the air either by a handmade humidifier or a commercial one if it seems to be necessary. Some automatically controlled humidifiers are on the market. If the relative humidity is low, the floors can be wetted. If very low, the fruit itself could be wetted. The difficulty with this last practice is that if the relative humidity should remain high after the water treatment, the free water persisting in the calyx or stem end of the fruit would provide an excellent place for growth of molds.

If the storage operator is willing to combat some added heat in the storage with refrigeration, he can raise the relative humidity by the addition of steam. If steam is available in the building, a jet can be directed into the storage chambers as required. Steam or water vapor can also be added to the room by heating water in the rooms.

The question is often asked about the effect of cooling the storage with outside air during the cold winter months. One of the disadvantages of this practice is that if dry air is introduced it may result in a marked lowering of the humidity of the room. If this drop is discovered and measured immediately and is compensated for by the introduction of water vapor into the air of the room, no harm should result from the standpoint of fruit shriveling.

Another question that frequently arises is the effect of rapidly moving air in the storage room on the drying of fruit. In a study with apples at Cornell[360] it was found that the effect of air movement on water loss was negligible. The greatest increase in water loss that could be attributed to air movement was 5% of the total lost. Some studies have attributed considerable effect to air movement, but it was not absolutely clear that the relative humidity was constant in all cases. For example, it has been shown that the water loss from apples was less in a "coil storage" than in a "blower storage."[360] With air movement more restricted in the coil room, it is more likely that the relative humidity was higher around the fruit than in the blower room where air movement was more rapid. It may be concluded that rapid cir-

[360] S. A. Pieniazek, *Refrig. Eng., 44,* 171 (1942).

culation of the air in an apple storage does not appreciably increase water loss if the relative humidity is kept high.

Measurement of Relative Humidity. A number of devices for the measurement of relative humidity are on the market. One of the most accurate methods is to determine the dew point and from appropriate tables to get the relative humidity. The most common method is the use of a sling psychrometer. Two thermometers are used, one with a dry bulb and one with a wet wick over the bulb which allows evaporation and thus determines the "drying power" of the air. From the difference in temperature of the "wet bulb" and that of the "dry bulb," the relative humidity can be figured out from appropriate tables supplied by the United States Weather Bureau or from simplified charts or "slide rules."[360a] The use of wet and dry bulbs is reasonably accurate only when there is a rapid movement of air over the thermometer bulbs. This may be accomplished by swinging the thermometers as with a "sling psychrometer" or more accurately by fanning a constant flow of air across the bulbs in an enclosed case. This is called an electrically aspirated psychrometer. Relative humidity may also be determined with an electrical resistance psychrometer. Direct readings of relative humidity may be taken from hair hygrometers. At best the more reliable of these latter are accurate only to about 2 to 3% and need periodic checking and adjustment with a psychrometer.

4. VENTILATION

The amount of ventilation required in the apple storage has been a moot question. By ventilation is meant the introduction of fresh air into the chamber. Of course, with air-cooled or common storages the introduction of fresh cool air at night during the autumn is an essential feature of the management of that technique. In the modern cold storage house, ventilation is practiced to a very limited degree.

Reasons for Ventilation. One reason for the frequent airing of the cold or common storage is to help control scald. It has already been mentioned that if certain gases persist around the fruit they will cause scald. Theoretically, if these gases were swept away fast enough from the fruit and replaced with fresh air, no scald would occur. Practically, this is out of the question because of the cost of refrigerating all the required warm air during the fall months and properly condi-

[360a] C. F. Marvin, *U. S. Dept. Commerce Weather Bur. Bull.*, 235, 1941.

tioning all the air brought into the storage in winter with regard to relative humidity. Scald is better controlled by other means.

Another reason offered for the ventilation of the storage chamber is to sweep out the carbon dioxide resulting from respiration and to bring in oxygen with the fresh air. It is true that a concentration of from 3 to 5% of carbon dioxide is quite toxic to certain apple varieties when the temperature is at 32°F. (0°C.). At a temperature of 40°F. (4°C.), however, a concentration of 15% is required to injure the fruit. When left shut tightly for several months, with no one entering the room, the carbon dioxide rarely reaches 2 to 3% in cold storage rooms. In one well-constructed cold storage chamber at Cornell, with the cork insulation thoroughly imbedded in asphalt, carbon dioxide has been observed to go as high as 8.5% when the room was kept tightly shut. In ordinary cold storage practice with the normal opening and closing of doors, the carbon dioxide seldom, if ever, reaches or exceeds 1 to 2%. Even at 32°F. this is not harmful to most varieties.

It may be concluded that with the normal opening and closing of doors in the cold storage, the fruit will be harmed little, if any.

Effect of One Lot of Fruit on Another in Storage. Another storage practice that influences the storage life of apples is the mixing of various lots of fruit in the same room. One lot of fruit may actually stimulate the ripening of another lot of fruit or it may speed up the production of the storage disease known as scald.

The stimulation of ripening varies from practically nil to a considerable effect. The particular cause of this stimulation effect is ethylene. The magnitude of the stimulation varies, depending upon the conditions described in Chapter VI.

It may be only under exceptional circumstances that really ripe apples are stored for any length of time. "Sun-colored" McIntosh which were held under the spread of the trees for a number of days after picking have been found to be a source of trouble in stimulating the ripening of less mature fruits. The same is true of other apples that are not put promptly into storage.

Another effect already mentioned is the stimulation in the production of scald. Studies at Cornell[361] have shown that Rhode Island Greening and Cortland apples stored in the presence of emanations of McIntosh apples scalded much faster than when stored alone.

To what extent it pays to store different lots of apples separately

[361] R. M. Smock, *Cornell Univ. Agr. Expt. Sta. Bull.*, 799, 1943.

has not yet been fully demonstrated commercially. The following recommendations seem appropriate. Ripe fruit should be removed from a room that is to be used for the long time storage of apples. Long delays in storage of any lot of apples should be avoided if for no other reason than that the lot may ripen sufficiently to affect other less ripe lots of fruit. If a number of storage rooms are available it may be worth while to store fruit of widely different maturities separately. This does not necessarily apply to separation of varieties. A ripe lot of McIntosh may affect another lot of McIntosh more than another variety would affect it. If a number of rooms are available, it might pay under some conditions to store varieties that are scald susceptible alone. This does not imply that such a procedure would control scald, but in some situations it might delay its appearance.

5. OTHER CONDITIONS AFFECTING LENGTH OF STORAGE LIFE OF APPLES

Conditions other than delayed storage, maturity, careful handling, temperature, relative humidity, presence of other lots of fruit, and composition of atmosphere affect the length of keeping quality in storage.

Variety. Varieties differ widely in their inherent length of keeping. Some, such as McIntosh, a fall sort, have a relatively short storage life because of their rapid respiration rate. Others, such as Northern Spy, that have a slower rate of respiration can be kept longer. Some varieties are limited in their storage life because of their inherent susceptibility to storage diseases. Some varieties may be kept beyond their normal storage season and appear normal but will have lost their characteristic quality. McIntosh is one of these. Good storage practice demands that all varieties should be removed from storage before they have passed their prime condition.

Orchard Culture. Heavy fertilization with nitrogen has been blamed for the poor keeping of some apples. With certain varieties at least, excessive use of nitrogen may influence the length of keeping through its effect on such storage troubles as scald and bitter pit or through its effect on fruit size. The claim is often made that fruits from potassium-fertilized trees keep longer than do fruits from unfertilized trees, but this has been proved to be true only where the trees were definitely lacking in potassium. Various systems of soil management might have some indirect effect on keeping quality through their effects on moisture supply and nitrogen in the soil.

Climate. No detailed studies have ever been made on the influence of various climatic conditions on the keeping qualities of apples in storage. The generalization has often been made that apples grown during a cool cloudy summer might have a shorter storage life than normally, partly because of the effect on fruit firmness and partly because of the influence on storage troubles such as brown core. It is known that apples grown in hot, dry climates are somewhat firmer than apples of the same variety grown in cool, cloudy areas.

Effect on Size of Fruit. It is quite generally recognized that large over-sized apples do not keep as well in storage as do normal-sized fruits. Very light crops or excessive thinning might result in poor-keeping fruits for this reason. Fruit from very young trees is often large in size and cannot be expected to keep as well as small fruits.

Washing for Spray-Residue Removal. It has been shown that the ordinary strength of hydrochloric acid (1%) used in spray-residue removal seems to have little or no influence on length of keeping quality of apples in storage. When emulsifiers are used, such as mineral oil, sodium silicate, or some of the commercial detergents, enough natural wax may be removed to cause serious wilting of the fruit in storage. Of course, the bruising and skin cutting which may occur in certain types of washers has a definite effect on shortening the storage life of fruits.

C. Storage Troubles of the Apple

1. STORAGE SCALD

One of the most destructive of storage troubles affecting the apple is the scald disease. It is a physiological disorder which appears first on the unblushed or green side of the fruit. It has a characteristic burned or scalded appearance (see Fig. 52). At first the discolored area is firm beneath the skin since the injury is confined to the skin. Later, the flesh immediately below the affected skin may become soft.

Storage scald seems to result from accumulations of certain gases (other than carbon dioxide or ethylene) which the apple itself generates in its life processes.[362-364] If these gases are allowed to

[362] C. Brooks, *J. Agr. Research, 26,* 513 (1924).
[363] C. Brooks, J. S. Cooley, and D. F. Fisher, *ibid., 16,* 195 (1919).
[364] C. Brooks, J. S. Cooley, and D. F. Fisher, *ibid., 18,* 211 (1919).

accumulate around the fruit, accumulations occur in the tissues of the fruit and scald ensues.

Orchard Factors Affecting Scald. The effect of *nitrogen* fertilization on scald development on apples is not clear cut. Some studies[365] have found no consistent effect of nitrogen fertilization on scald and others[366] have found increased scald with nitrogen applications. Still others have found reduced scald with nitrogen applications to certain varieties.[367,368] One would expect that nitrogen fertilization would

Fig. 52. Scald on Rhode Island Greening apple (left). Scald-free apple (right).

make scald worse since it makes apples greener at harvest time and green apples are more subject to scald than well-colored ones. However, this is apparently not necessarily true.

It has been found that apples growing on potassium-deficient soil were less subject to scald in storage.[369] This is not surprising when one remembers that apples growing on potassium deficient trees usually are better colored and ripen somewhat prematurely. Borax addition to a soil not particularly deficient in boron has been found to reduce scald on apples.[370] However borax would not be applied for

[365] R. M. Smock and F. W. Southwick. *Cornell Univ. Agr. Expt. Sta. Bull.*, 813, 1945.
[366] J. H. Gourley and E. F. Hopkins, *Ohio Agr. Expt. Sta. Bull.*, 479, 1931.
[367] E. F. Savage, *Proc. Am. Soc. Hort. Sci., 38,* 282 (1941).
[368] R. M. Smock and D. Boynton, *ibid., 45,* 77 (1944).
[369] F. Kidd and C. West, *Rept. Food Inv. Board 1937,* 97 (1938).
[370] L. P. Batjer and M. H. Haller, *Proc. Am. Soc. Hort. Sci., 40,* 29 (1942).

this reason. The reduced scald seemed to be due to the advanced maturity caused by the boron application.

Apples "forced" late in the season by heavy rains or irrigation are said to be more susceptible to scald in storage.[364]

Large apples are usually more susceptible to scald than small ones. That does not mean that small fruits may not develop as much as 100% scald on occasion, however.

Defoliation of individual limbs on the tree during the growing season usually reduces susceptibility to scald in storage.[365]

Sprays with thiocyanate materials during the growing season have been found to reduce scald.[371] Because of the foliage injury resulting from this spray and because of the advanced maturity of the fruit as a result of spraying, it is doubtful if this fact has any practical significance.

Prestorage Factors Affecting Scald. Apple growers have known for a long time that fruit picked early was more susceptible to scald than late-picked fruit. Even the latest Rhode Island Greenings will develop scald in some seasons, however. Late picking does not seem to be an answer to the problem with a variety like Greening since this variety is sold as a green cooking apple.

Delayed Storage. Delayed storage gives inconsistent results in reducing scald. Doubtless the amount of air movement[364] in the fruit stack during the period of delay determines the success of delayed storage in reducing scald. It would seem just as wise to let the fruit ripen on the tree as on a warm packing-house floor if this technique is to be followed. Delayed storage followed by waxing[372] gives some control of scald and yet prevents the wilting of the fruit that may take place after the period of delay.

Waxing varieties like Rhode Island Greening with certain wax emulsions has been shown materially to reduce the amount of scald.[365]

The use of *oiled paper* either as a fruit wrap or as shreds of paper distributed throughout the package has been considered the standard means of scald control ever since the classic work of Brooks, Cooley, and Fischer.[364] Where apples are wrapped in box packing, oiled paper wraps are commonly used. Shredded oiled paper (0.5 pound per bushel recommended) is often but not always used on scald-susceptible varieties in the sections where apples are not wrapped.

[371] R. B. Dustman and I. J. Duncan, *Plant Physiol., 15,* 343 (1940).
[372] C. W. Hitz and I. C. Haut, *Proc. Am. Soc. Hort. Sci., 38,* 249 (1941).

Paper impregnated with 1% by weight of tasteless, odorless mineral oil is used. There have been a number of objections raised to shredded oiled paper; its cost, its failure to control scald in severe cases, the fact that it absorbs foul odors in the room, and the fact that some buyers object to quantities of paper in the package.

Storage Factors Affecting Scald. Scald usually increases in intensity in storage up to about 66° F. and beyond this temperature it decreases.[364] Apples stored continuously at room temperature in the fall after harvest will not develop scald. In the lower temperature range of storage (32–40° F.) scald has sometimes been reported as being worse at 32° than at slightly higher temperatures.[373] Fluctuating temperatures in storage usually result in less scald but this is not considered a means of controlling the trouble.[364]

Ventilation with fresh air is a possible means of controlling this trouble since it is caused by accumulations of certain gases around the fruit.[364] It is not a feasible means of control because it means refrigerating vast quantities of fresh air during the relatively warm months of September and October. Mere circulation of the storage air may delay the appearance of scald slightly but it has little or no effect on the final amount.

The presence of *carbon dioxide* seems to delay the appearance of scald[374] (see pages 188–189). In controlled atmosphere storage of Cortland and McIntosh it has been found that the lower the *oxygen* level and the more rapidly the oxygen is dropped to a low level, the less rapidly scald develops (in Cornell studies). Scald is very likely to be severe in controlled atmosphere storage particularly when the oxygen level is rather high because of the very restricted atmosphere (*i.e.,* lack of ventilation with fresh air).

From general observation and from experimental work it would seem that scald is very much worse at high *relative humidities* than at low.[364]

One lot of fruit may increase the amount of scald on another. For example, McIntosh has been found to increase the scald found on Greenings stored with them.[365] This may be due to the greater production of volatile materials by the former. See Figure 53.

Air purification by means of activated carbon has been found to reduce the amount of scald on apples.[365] With this treatment about

[373] C. A. Eaves and H. Hill, *Can. Dept. Agr. Tech. Bull.,* 28, 1940.
[374] F. W. Allen, *Proc. Am. Soc. Hort. Sci., 40,* 193 (1942).

1.5 pounds of activated carbon is used per 250 bushels of fruit. Air is passed through a canister containing this amount of carbon at the rate of about 25 cubic feet per minute. This method has the advantage

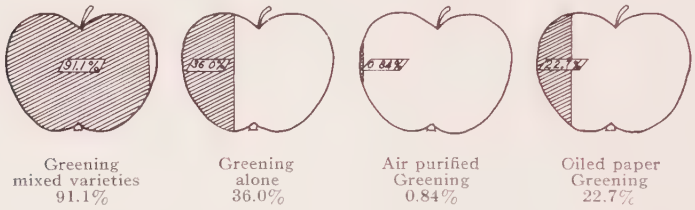


Fig. 53. Amounts of severe scald occurring on Rhode Island Greening when stored alone, with mixed varieties, when air purified with activated carbon, and when treated with oiled paper.

over oiled paper in that it is somewhat cheaper and more convenient to use. It also removes the foul odors from the room and tends to remove the naturally evolved ripening gases from the chamber.

2. BITTER PIT

Bitter pit, stippin, and Baldwin spot are all the same trouble and affect such varieties as Baldwin, Northern Spy, Rhode Island Greening, York Imperial, and others to a lesser extent. Bitter pit is characterized by the development of small brown spots or streaks

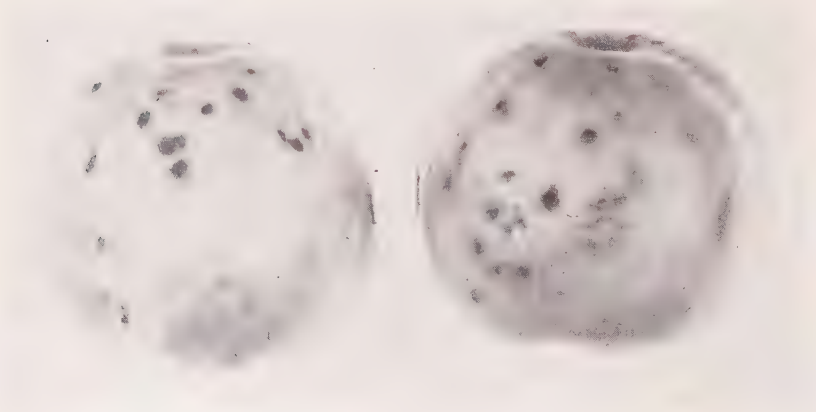


Fig. 54. Bitter pit on apples after storage.

in the flesh of the apple, particularly just beneath the skin. Occasionally spots may be found deep down in the flesh of the fruit which are not visible from the outside. In its incipient stages the disease is distinguished by the collapse of groups of cells beneath the hypodermal layers of the fruit. In the later stages of development the walls in the affected area not only are collapsed but become torn. Included between the collapsed walls one may observe starch grains which persist through the remainder of the life of the fruit.[375] Affected areas frequently if not always are associated with vascular bundles in the flesh of the fruit. During the early stages of development the epidermis and the hypodermis are not affected; but later, with the collapse of large areas of flesh, these tissues may become distorted.

The exact cause of bitter pit is not known but all of the evidence points to its being caused by some maladjustment in the normal water relations of the fruit. The hypothesis has been presented that any treatment which accentuates the "pulling power" of the leaves for water (because of their advantage in osmotic concentration) at the expense of the fruits will increase the susceptibility of fruit to bitter pit in storage.[376] This emphasizes the fact that susceptibility is induced in the orchard although the trouble may not appear until the fruit has been stored.

Orchard Factors Affecting Bitter Pit. Heavy *nitrogen fertilization* increases the susceptibility of apples to this trouble in storage. The effects of nitrogen fertilization, of course, may not be seen except on trees that were initially at a low nitrogen level.[376] *Large fruits* are more susceptible to this trouble in storage than are small ones. Fruit picked in an *immature* condition are more subject to this disorder.[377] *Excessive shading* is likely to result in more pitting. *Heavy pruning* seems to induce more bitter pit. While pruning does eliminate excessive shading, it often results in larger fruit and a larger supply of nitrogen to the remaining fruits.

Ringing of large limbs during the summer months increases susceptibility to bitter pit. Ringing increases the osmotic concentration of both fruits and leaves but it seems to increase that of the leaves more than that of the fruits (Fig. 55).[376] Partial ringing of the fruit stems during the early summer greatly increases susceptibility

[375] R. M. Smock and A. Van Doren, *ibid., 34,* 179 (1937).
[376] R. M. Smock, *Cornell Univ. Agr. Expt. Sta. Mem., 234,* 1941.
[377] F. W. Allen, *Proc. Am. Soc. Hort. Sci., 28,* 639 (1932).

in storage. This fact has no practical significance but it helps reveal something of the nature of the trouble. Such ringing would decrease the supply of carbohydrates to the fruits and increase it in the leaves. This would result, theoretically at least, in a greater pulling power for water in the leaves than in the fruits.

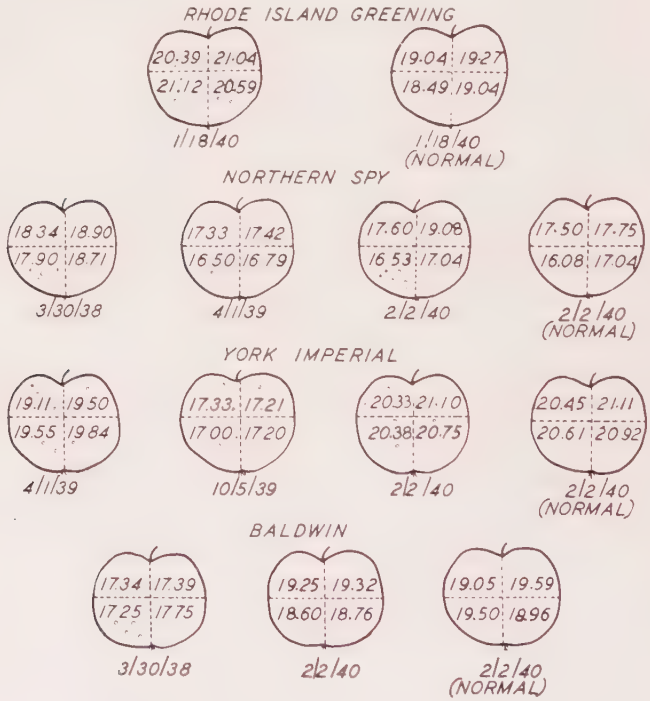


Fig. 55. Osmotic pressures (in atmospheres) in different quarters of fruits affected with bitter pit and normal fruits. Small circles indicate distribution of pits on fruits.[376]

The *time* and the *amount of rainfall* during the growing season seems to play a part in the development of this disorder in storage.[378] Heavy rainfall or irrigation particularly late in the season seems to induce large amounts of bitter pit in storage.

Prestorage Factors Affecting Bitter Pit. Delayed storage for a week or more results in considerable increases in bitter pit in stor-

[378] C. Brooks and D. F. Fisher, *J. Agr. Research, 12,* 109 (1918).

age.[376] *Waxing* fruits slows down the appearance of bitter pit in apples, but it is doubtful if waxing could be justified for this reason alone.[379]

Storage Factors Affecting Bitter Pit. Prompt storage at a temperature of 32–34°F. (0–1°C.) is one of the best insurances against rapid development of bitter pit. The final amount may be just as high at 32° F. as at 40° F. (4°C.) but it does not appear as quickly and the fruit may be disposed of before it develops visible bitter pit. *Controlled atmosphere storage* may be expected to delay the appearance of bitter pit but it does not really control it. The only storage factor

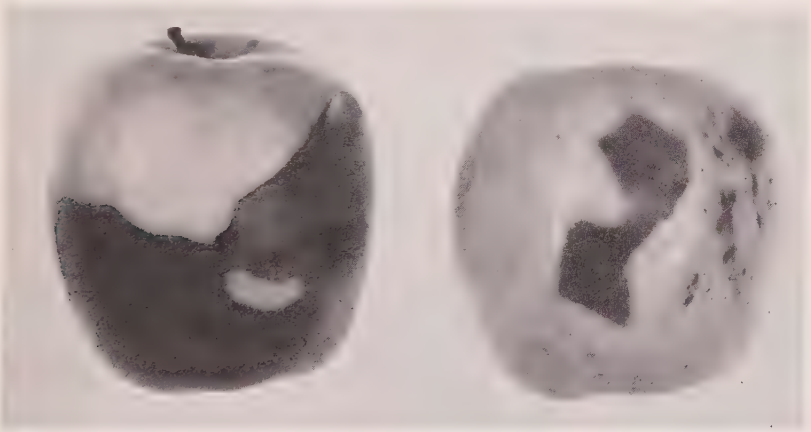


Fig. 56. Soft scald occurring on apples after storage at 32°F. (0°C.).

which may be manipulated really to reduce the final amount of bitter pit is the *relative humidity*. It has been found that the higher the relative humidity, the less bitter pit develops.[376]

Another indication that bitter pit is related to a disturbance in the normal water relationships is the fact that the osmotic concentration of the bitter part of the fruit is usually lower than other parts of the fruit (see Fig. 55). The pits in varieties like Baldwin and Northern Spy are often confined to one quarter of the fruit at the calyx end of the fruit. The fact that this quarter of the fruit is normally (before pits appear) lower in osmotic concentration may help explain why that portion is more susceptible to the trouble. In York Imperial the pits are usually well distributed over the entire fruit and it may be

[379] R. M. Smock, *Proc. Am. Soc. Hort. Sci., 35,* 176 (1938).

more than coincidental that the osmotic concentration varies little from one part of the fruit to the other in this variety.[376]

3. SOFT SCALD

Soft scald is another physiological disorder of the apple found on such varieties as Rome Beauty, Jonathan, Winter Banana, Northwestern Greening, Golden Delicious, and Wealthy. It produces blister-like sunken areas that extend in irregular patterns over the fruit (see Fig. 56). These areas are often curved and occasionally result in the formation of islands of normal tissue. In the earliest stages only the skin is discolored and it resembles apple scald, but this trouble does not seem to be related in any way to storage scald. It is probably merely a type of soggy breakdown.[380,381] In the later stages the flesh beneath the affected skin becomes very soft and discolored and leaves large depressed areas over the fruit. Secondary fungus infection often follows this stage.

Prestorage Factors Affecting Soft Scald. Delays in storage ordinarily greatly increase the amount of soft scald in storage so prompt storage must be practiced with most susceptible varieties. With some varieties delays of storage have been reported to increase resistance to the trouble.[381] One or two days of exposure of the apples to an atmosphere containing 20% or more of carbon dioxide before storing at 32° will often reduce the amount of soft scald.[382]

Storage Factors Affecting Soft Scald. Soft scald can usually be prevented by storing at temperatures of 36°F. (2°C.) or above. Hence, it seems to be specifically a *low-temperature disorder*.[380,381]

4. SOGGY BREAKDOWN

Soggy breakdown which is often apparent in storage on such varieties as Grimes Golden, Northwestern Greening, Jonathan, Wealthy, and Golden Delicious is thought by some workers[380,381] to be a trouble identical in cause but different in expression with soft scald. In Grimes Golden and Golden Delicious the inner part of the flesh becomes brown and soft, although this condition may not be visible externally. In severe cases a complete ring of soft, brown,

[380] H. H. Plagge, T. J. Maney, and B. S. Pickett, *Iowa Agr. Expt. Sta. Bull., 329*, 1935.
[381] H. H. Plagge and T. J. Maney, *J. Agr. Research, 55*, 739 (1937).
[382] C. Brooks and C. P. Harley, *ibid., 49*, 55 (1934).

spongy tissue is present, which is in marked contrast to the healthy white tissue (see Fig. 57). In the very late stages the trouble may become apparent externally. When first taken out of storage the soggy breakdown areas are watery, but on continued exposure to a dry atmosphere they become dry and shrunken. Affected apples have an alcoholic taste which is apparent in both normal and affected tissue.

Orchard Factors Affecting Soggy Breakdown. Apple varieties from the same orchards in different years, and from different orchards in the same year, exhibit marked differences in susceptibility to soggy breakdown.[381] This means that there is a marked *climatic effect* on this disorder. Another indication of this fact is the observation that

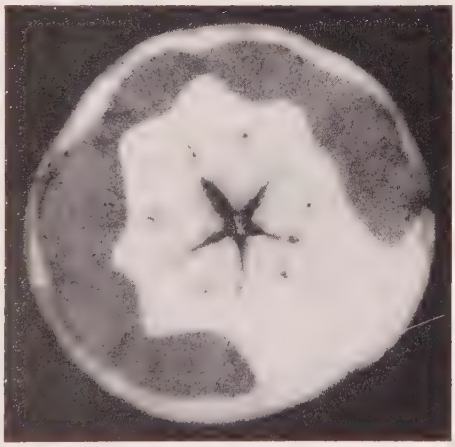


Fig. 57. Soggy breakdown in the Wealthy apple.

varieties grown in the Middle West seem to be more susceptible to the trouble than the same varieties grown in New York and New England. *Large fruits* of Northwestern Greening are more subject to the trouble than small ones; but this size factor was not noted in other varieties.[381]

Prestorage Treatments Affecting Soggy Breakdown. The effect of *delayed storage* on this trouble is not entirely clear from the experimental evidence. The amount of soggy breakdown following delayed storage may depend upon variety and the length of the period of delay.[382] In one study prompt storage of varieties like Jonathan and Northwestern Greening resulted in greater susceptibility to soggy breakdown whereas similar treatment with Wealthy and Grimes Golden caused these varieties to be more resistant.[380,381] Prestorage

treatment with *carbon dioxide* (20% or more) before storage at 32°F. (0°C.) may reduce the intensity of this trouble.[382] The more mature the fruit is at harvest time the more susceptible the fruit is to this trouble.[382]

Storage Factors Affecting Soggy Breakdown. This disorder seems to be specifically a *low-temperature* disorder and storage at temperatures of 36°F. (2°C.) or higher seems to prevent the trouble.[380,381] *Gradual cooling* of the fruit when first placed in storage seemed to reduce the trouble in one study.[382] The use of oiled wraps or continuous circulation of the storage atmosphere had little or no effect on this disorder.[380]

5. BROWN CORE

Brown core is also known as "core browning" and "core flush." It is characterized by a premature browning of the flesh around the core. Its first appearance is noted as a slight discoloration of the flesh between the seed cavities. Boron deficiency sometimes has quite similar symptoms when there is no sign of external "cork" spots. Later considerable portions of the flesh around the core become rather brown in color and the fruit is unmarketable (see Fig. 50). It affects McIntosh primarily but may occur in Fameuse, Twenty Ounce, Rhode Island Greening, Baldwin, and other varieties. Ordinarily it does not become very severe until after Christmas in storage.

Brown core may actually have different causes in different varieties. For example, low-temperature storage increases the appearance of this trouble in McIntosh and seems to decrease it in Fameuse or Rhode Island Greening. It would seem that symptoms similar to that of brown core may occur in a variety like Northwestern Greening as a preliminary step in the development of mealy breakdown. In other words, it may occur as a sign of mere senility in some varieties. This trouble is treated in this discussion as specifically a low-temperature disorder.

Orchard Factors Affecting Brown Core. Specific climatic studies have not been made in connection with this trouble but it is known that it varies considerably in intensity from season to season in the same orchard. There is some indication that it may be worse following growing seasons that have been rather cloudy and cool.[383]

[383] R. M. Smock, *Proc. Am. Soc. Hort. Sci., 47,* 67 (1946).

It has been found that brown core seemed to be worse following rainy weather during the ripening period on the tree.[384] It is not clear from this study whether it was specifically the rainfall or the cooler weather and reduced light intensity which caused more brown core. Shading of entire limbs with cheesecloth has greatly increased the amount of this trouble in storage. Whether it is the exclusion of light or the lowering of the temperature that induces susceptibility in this case is not known.[383] Heavy fertilization with nitrogen seems to increase susceptibility to the trouble.[385]

However, in one study it has been reported that in years of severe brown core reduced nitrogen fertilization did not give lessened amounts of the trouble.[384] It is generally found that the more mature the fruits are at harvest time the less of this trouble they develop in storage.[383] Large fruits are usually more susceptible to the trouble than small ones.

Prestorage Treatments Affecting Brown Core. It has been suggested that a five-day delay before storage would greatly decrease the amount of brown core.[386] Other studies have shown that delayed storage did reduce the intensity of the trouble but that this finding had little practical implication.[383] The delay in storage at a high temperature so reduces the storage life, that McIntosh apples would have to be sold by Christmas time anyway because of overripeness and brown core is seldom severe by January even with prompt storage.

Storage Factors Affecting Brown Core. Brown core in most varieties is a true *low-temperature* disorder. It has been pointed out previously that in some varieties the preliminary symptoms of mealy breakdown are almost identical with brown core and mealy breakdown is not a low-temperature disorder. Brown core can usually be avoided by storage at temperatures of 36°F. (2°C.) or preferably 40°F. (4°C.). With McIntosh this can be done with no sacrifice in keeping quality by use of controlled atmosphere storage at 40°F.

Brown core does not seem to be a result of carbon dioxide accumulations at 32 F. (0 C.) but high accumulations of this gas may cause brown core when oxygen levels are high, particularly at 40°F. (4°C.).[383]

[384] W. H. Smith, *ibid., 41,* 99 (1942).
[385] R. M. Smock and D. Boynton, *ibid., 45,* 77 (1944).
[386] E. J. Rasmussen, *New Hampshire Agr. Expt. Sta. Tech. Bull., 67,* 1937.

6. MEALY BREAKDOWN

Mealy breakdown is characterized by the normal, juicy pulp tissue of the fruit becoming soft, dry, and crumbly. The early stages of breakdown are characterized by a mealiness in the flesh and then later by some brown discoloration. In its early stages it may have much the same symptoms as brown core. In the later stages the outer portions of the flesh may actually burst and split. This trouble seems to affect almost all apple varieties but is most commonly seen in varieties like Rhode Island Greening, Grimes Golden, York Imperial, Delicious, Jonathan, and McIntosh.

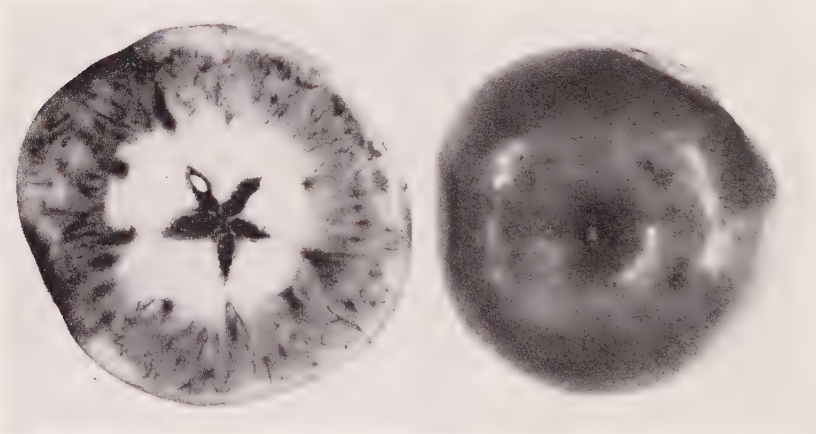


Fig. 58. Mealy breakdown in Rhode Island Greening apples.

Orchard Factors Affecting Mealy Breakdown. In one sense mealy breakdown is merely premature senility or old age. *Large, oversized fruits* are more likely to get this trouble than are normal-sized fruits. Apples grown under certain *climatic* and *soil conditions* seem more troubled with mealy breakdown than do others, but the exact conditions which cause susceptibility have not yet been defined. *Overripe apples* placed in storage develop more of this trouble than those picked at the right time.

Storage Factors Affecting Mealy Breakdown. Susceptible apples should be stored promptly at the *correct temperature*. Almost any variety of apples (as noted above) will develop this trouble if held in storage too long, so care should be taken to market the fruit

before the apples begin to become mealy. Apples held at 32° F. (0° C.) will develop this trouble less quickly, of course, than at higher temperatures and more slowly in controlled atmosphere storage than in ordinary storage.

7. INTERNAL BREAKDOWN

Internal breakdown of apples is characterized by the collapse and browning of the interior of the flesh (see Fig. 59). It frequently develops at bruised spots and from these areas extends inward. In sound fruit it often appears first on the riper side and often first on the blossom end of the fruit. The brown, collapsed flesh loses its flavor very rapidly. In an affected fruit slight pressure on an apparently

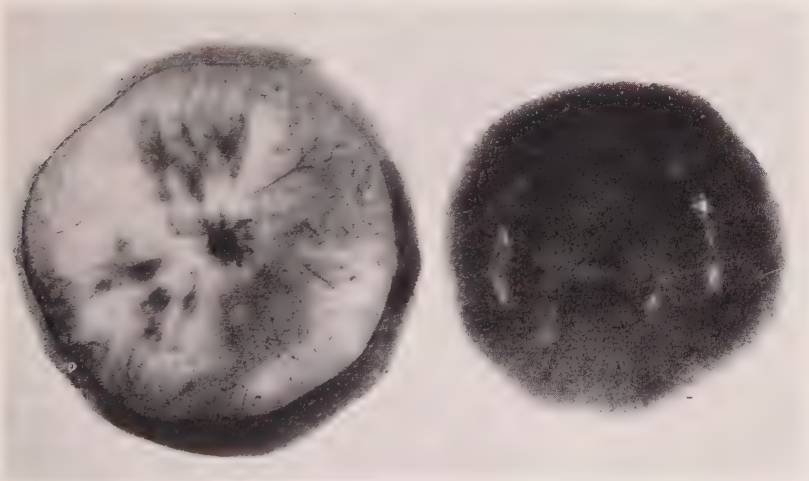


Fig. 59. Internal breakdown in Northern Spy apples.

normal section of the surface shows that the interior of the fruit is collapsed. Internal breakdown is similar in many ways to mealy breakdown but the flesh is not necessarily so mealy and usually there is no splitting of the skin. Once the breakdown has reached the surface of the fruit, fungi causing rots readily enter the affected surface. It may be seen in many varieties but is most frequently seen on Stayman Winesap, Twenty Ounce, and Northern Spy.

Like mealy breakdown this disorder is also a form of premature

senility. The cause is unknown and the cause may even differ from variety to variety.

Orchard Factors Affecting Internal Breakdown. Internal breakdown is particularly common on *overmature apples* and those *forced late* in the season.[387]

Storage Factors Affecting Internal Breakdown. As stated above the cause of internal breakdown may vary from variety to variety. For example, it has been noted with Northern Spy at Cornell that more of this trouble appeared at 32°F. (0°C.) than at 40°F. (4°C.), yet with most varieties just the reverse would be true. With Stayman Winesap it has been reported that *ventilation* decreased the trouble.[387] *Controlled atmosphere* storage with a temperature of 40°F. has prevented the trouble in Northern Spy in Cornell studies.

8. INTERNAL BROWNING

Internal browning is specifically a low-temperature disorder of certain varieties. It is particulary serious in Yellow Newtown apples grown in the Pajaro Valley of California. It is also found in the east in Rhode Island Greenings. The affected tissues are brown but remain firm and radiate out from the core area. It differs from brown core in that the diseased portions radiate farther from the core, and they are firmer than those of other internal storage disorders.

Orchard Factors Affecting Internal Browning. Since this trouble is so common in the Pajaro Valley of California (Watsonville area) it is thought that the *climate* of that section may have something to do with its severity. The growing season in that section is very cool and often foggy.[388,389] Fruit from *old trees* and from trees bearing a *light crop* seem to develop more of this trouble than from other trees. Fruit from very *weak trees* seem to develop more of the trouble than fruit from trees of moderate vigor. Late-picked fruit seems to develop more than early picked. *Shading* trees with a tent greatly increased susceptibility whereas shading individual fruits with black shades (which raised their temperature by 10°F.) increased resistance. Fruit from the shaded, unexposed interior parts of the tree develop more of the trouble.

Prestorage Factors Affecting Internal Browning. Delayed storage increases the amount of internal browning in storage.[388,389]

[387] C. Brooks, *U. S. D. A. Farmers' Bull.*, 1160, 1935.
[388] E. L. Overholser, A. J. Winkler, and H. E. Jacob, *Calif. Agr. Expt. Sta. Bull.*, 370, 1923.
[389] A. J. Winkler, *J. Agr. Research, 24*, 165 (1923).

Storage Factors Affecting Internal Browning. This disorder is a *low-temperature* disorder and can be avoided by using storage temperatures of 36° to 40°F. (2–4°C.).[388,389] Yellow Newtowns can be stored at 40°F. with no sacrifice in length of storage if controlled atmosphere storage is used.

9. JONATHAN SPOT

Jonathan spot occurs primarily on Jonathan apples but may also affect King David, Spitzenburg, Wealthy, Rome, and occasionally others. The spots start as minute black areas, but often increase in size to one-eighth inch or more in diameter. The discolored skin spots

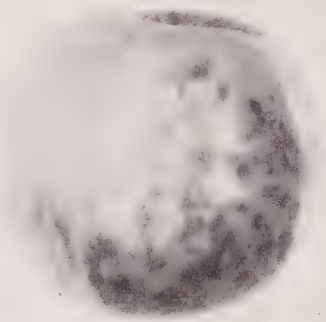


Fig. 60. Jonathan spot on Jonathan apple.

usually but not always center around the lenticels of the fruit. The spots are usually more numerous on the red or colored side of the fruit and toward the stem end than elsewhere. The spots do not extend into the flesh but affect merely the skin (see Fig. 60). In its late stages secondary infections may occur from various fungi, and rotting and complete breakdown of the areas begin.

The spotted tissue results from a change in color of the skin anthocyanins. It has been found that the pulp cells immediately below the spots were lower in acidity than adjacent areas.[390] This may account for the change in color from red to bluish black since it is characteristic of anthocyanin pigment to change from red to blue as acidity decreases. For example, it can be demonstrated that exposure to ammonia fumes will produce spots very similar to those of Jonathan spot

[390] W. T. Pentzer, *Proc. Am. Soc. Hort Sci., 22,* 66 (1925).

in the early stages. If the exposure is not very long the fruit may actually recover from the ammonia injury and regain its red coloration. The explanation is sometimes given that the reason immature fruits develop less Jonathan spot than more mature fruit is that they are more acid at the time they are placed in storage.[391] Color changes due to actual change in *p*H of apple cells have not been proven, however.

Orchard Factors Affecting Jonathan Spot. Late-picked apples are much more subject to this trouble than early-picked ones.[391] Highly colored apples are more subject to it than fruit with little anthocyanin development.[391]

Storage Factors. Storage at a low temperature (32°F.) is most conducive to control of this trouble.[391] Controlled atmosphere storage has been found completely to eliminate this trouble.[392]

10. SPOT DISEASE OF NORTHERN SPY

This spot disease seems closely related to Jonathan spot but the spots are usually smaller and more numerous. In the early stages the spots are not bluish purple as in Jonathan but are brown. In the later stages they may be brownish black or black. They are usually more

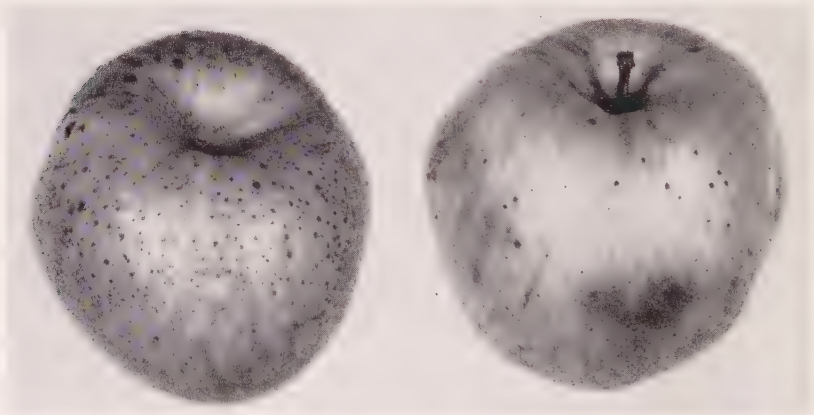


Fig. 61. Left, physiological Spy spot on Northern Spy apple; right, spots on Northern Spy due to *Alternaria* fungus.

[391] H. H. Plagge and F. Gerhardt, *Iowa Agr. Expt. Sta. Bull.*, 131, 1930.
[392] R. M. Smock and A. Van Doren, *Cornell Univ. Agr. Expt. Sta. Bull.*, 762, 1941.

numerous on the stem end of the fruit and are worse on the highly colored portions of the fruit. It seems to be confined primarily to Northern Spy but a similar trouble has been seen on Rome Beauty (see Fig. 61).

Orchard Factors Affecting Spy Spot. The only orchard treatment in Cornell studies which seems to intensify this trouble was ringing large limbs in early summer. Shading and defoliation had no effects on the trouble. Late-picked fruits develop much more of the trouble than early-picked fruits. It is worse on highly colored fruits than on poorly colored ones.

Storage Factors Affecting Spy Spot. Prompt storage at a low temperature helped to delay the appearance of this trouble. Controlled atmosphere storage seems entirely to prevent it. It was not increased by exposing the fruits to the vapors of ripe apples as is scald; hence air purification was of no benefit.

11. RODENT CONTROL IN STORAGE

Mice and rats are sometimes a source of loss to apples in storage. It has been estimated that a single rat could do one hundred dollars worth of damage to stored apples. Field mice are especially likely to be a problem when apples are put directly into the storage from the field. The grading and packing operation eliminates field mice from the field containers. Mouse damage is evidenced by a chewing away of the flesh. Mice may take just a few nibbles out of each apple and thus destroy many fruits. Such fruits are not only unmarketable because they are unsightly but because they frequently decay. Rats usually gnaw into the fruits to get the seeds to eat.

A number of methods of rodent control have been suggested. All points of entry into the storage for rats and mice should of course be eliminated. It is always wise to use insulation material that does not invite mice as a place for nesting. Without any experimental evidence to justify the practice some storage operators use the exhaust gases from gasoline engines to kill rodents. Some operators merely pipe in the exhaust fumes from trucks and secure sufficient *carbon monoxide* in this way to kill rodents. While this practice may kill all rodents it would seem to be a questionable one. In the first place there is considerable danger to humans. It has been demonstrated in actual practice that it is dangerous to use gasoline lift trucks or transporters in cold storages where men are working. It is for this reason that battery-

operated transporters are used. While the exhaust fumes might be employed at night, one could not be sure without actual analysis for carbon monoxide whether toxic amounts remained when men started working in the rooms the next day. Danger to the men is probably greater than it is to the fruit. However, the exhaust fumes of gas engines contain not only carbon monoxide but carbon dioxide and ethylene (among other gases). It has been shown[392a] that apples can tolerate up to 7% of carbon monoxide without actual injury but the ethylene present might have a stimulatory effect on fruit ripening if present in sufficient amount.

A safer and more highly developed method of rodent control is the use of *methyl bromide* gas. One-quarter pound of this gas is used per 1000 cubic feet of air space in the room. When the room is full of fruit the total air capacity is reduced by some 50%. This treatment is maintained for about five hours with the room very tightly closed. It is extremely important to ventilate the rooms thoroughly with fresh air after the treatment. Traces of the gas may be detected with a halide detector to see if ventilation has been completed.[392b,392c] Treatment with this gas is given after the apples have been in storage about one month.[392d]

Another method of rodent control is fumigation with *carbon dioxide*. This gas is used in a tightly sealed room for three to five hours at a concentration of 20%. Twenty-five to thirty pounds of dry ice per 1000 cubic feet of air space will provide this concentration.[392e]

Baiting of rodents with strychnine-treated oats is sometimes practiced but it is often difficult to place the bait in the places that will attract all the rodents.

12. CARBON DIOXIDE AND LOW-OXYGEN INJURY

The amount of carbon dioxide injury is a function of both carbon dioxide concentration and temperature. It may require only 5% of carbon dioxide to produce severe injury on McIntosh apples at 32°F. (0°C.) but 15% at 40°F. (4°C.). Carbon dioxide injury seems to differ with varieties and possibly with the temperature used. For ex-

[392a] M. H. Haller and D. H. Rose, U. S. D. A., *private communication*, 1947.
[392b] F. W. Southwick, F. B. Schuler, and G. N. Alpaugh, *Proc. Am. Soc. Hort. Sci., 45,* 136 (1944).
[392c] R. M. Borg and L. Southwick, *ibid., 45,* 146 (1944).
[392d] F. W. Southwick, *ibid., 46,* 152 (1945).
[392e] S. A. Pieniazek and E. P. Christopher, *ibid., 48,* 93 (1947).

ample, injury on McIntosh at 40°F. (4°C.) is first seen on the skin. It is characterized by a yellowish brown depressed condition of the skin. This affected area is usually rough and crinkled and yet the flesh is very firm beneath the injured portion. Injury to the flesh of McIntosh at low temperatures is characterized by almost complete browning of the flesh. Unlike internal browning there are no radiating lines of affected tissue but all tissues of the fruit turn brown. This is similar to so-called "brown heart." Injury to varieties like Rhode Island Greening, Wealthy, and Jonathan is characterized by dry, pithy portions around the core of the fruit. Large areas of this dry tissue cause collapse of the cells and there will be large air spaces within the affected portion. Carbon dioxide injury usually seems to be worse on the unblushed portion of McIntosh apples and seems to be worse on immature fruits than on mature.

Low-oxygen injury on Cortland and McIntosh is characterized by brown blister-like depressions in the skin not unlike that of soft scald. Injury is not likely to come in most varieties until the concentration of oxygen gets as low as 1% or thereabouts. Such injury would not likely occur except in controlled atmosphere storage or when the fruit was wrapped in gas-impervious materials.

13. BLUE MOLD ROT

Blue mold (*Penicillium expansum*) is probably the most common and most destructive of all the rotting organisms that attack apples.[393] It appears on all varieties as soft, watery spots of a light brown to light yellow color. At first the spots are shallow but later may extend deeply into the fruit. If the air around the fruit is moist and warm, a surface growth of the mold may appear on the rotted portion. It occurs also as small tufts of whitish and later blue-green, grain-like structures (spores) on the rotted area. When the decay becomes well advanced, a musty odor and taste develops.

Control. All fruit must be carefully handled, for fruit with skin cuts and bad bruises is likely to become affected with this blue mold rot. Although the spores may enter the unbroken skin, most of the entrance of the organisms is likely to be through breaks in the skin. Prompt storage also helps to reduce rotting since the fungus or mold grows more rapidly at higher than at lower temperatures. It does grow slowly, however, even at 32 F. Since the air is laden with spores of

[393] F. D. Heald and G. D. Ruehle, *Wash. Agr. Expt. Sta. Bull.*, 253, 1931.

this fungus, it is difficult to have fruit enter storage without spores on the surface of the fruit. Most measures of sanitation have given disappointing results. The mold grows more rapidly in moist air, but the relative humidity must be kept high from the standpoint of fruit shriveling.

When apples are washed for spray residue removal, it is possible to add sodium chlororthophenylphenol to the sodium silicate and obtain a reduction in subsequent decay of apples.[393a] This material cannot be used in the hydrochloric acid portion of the wash. Care must be taken to rinse it off the fruits. Workers must be careful with this material lest they develop dermatitis.

14. SURFACE-GROWING MOLDS

A number of molds, or fungi, such as blue mold, can grow on the surfaces of the fruit, on boxes, and on walls if the relative humidity is very high and even though the temperature is at 32°F. (0°C.). As has been stated the relative humidity is customarily maintained at 85 to 90% in spite of some shriveling to minimize the growth of these surface molds. They have been called "whiskers" because of their excessive growth. While they may not actually enter the skin of the fruit, they make both the package and the fruit unattractive and their growth seems to give the atmosphere a musty smell. It may be, however, that this smell is due in part to odors from the wood in the packages which is noticeable when the relative humidity is high.

Control. Various attempts have been made to control these surface-growing molds. Old containers have been disinfected by either dipping them in a formalin solution or a chemical, such as sodium or calcium hypochlorite, or by steam sterilization. The storage rooms, too, have been disinfected with sprays of calcium hypochlorite or copper naphthenate. While these treatments may cut down growth of these molds, they have apparently not proved an adequate control. Although the room and the containers may be sterile at harvest time, the fruit is heavily laden with spores of these fungi which are probably introduced into the room with the opening of the storage-room doors.

In some storages these molds have been successfully controlled by ozone. The ozone is supplied from electrical ozone-generating machines. Egg storages frequently use this technique to cut down the growth of "whiskers," or molds on eggs. Ozone is used in apple stor-

[393a] H. English, *Phytopath., 38,* 914 (1948).

ages in concentrations up to two parts per million in the atmosphere.[394] Since it is difficult to measure the concentration of ozone, it is a common practice to have just enough in the atmosphere to be barely detected by odor. Several apple storage operators have found from one half to one hour a day enough time to run their ozone machines. In egg rooms, at least, it has been found that the ozone need not be present continuously at the suggested concentration. The machine may run for an hour or two a day, frequently before the men working in the storage rooms arrive for work and after they leave in the afternoon. Measures must be taken to see that the ozone is well distributed throughout the room. The ordinarily used concentrations do not irritate the mucous membranes. When used in the apple storage a cloud of vapor may appear, but this is merely oxidized apple vapors and does no harm. After continued use of ozone in the storage chamber, the rubber gaskets around the doors may begin to disintegrate and require replacement. If they are of synthetic rubber, this trouble is not experienced so soon.

15. ALTERNARIA

The decay caused by the fungus *Alternaria* is characterized by small, firm, slightly sunken areas which may be brown around the edges. These areas are usually covered for the most part with a rough, black crust. The decay may have other symptoms, however, and absolute identification of the trouble would have to be made by a pathologist. The fungus usually gains entrance into apples through injuries to the skin made by worms, arsenical injury, scald, soft scald, and mechanical breaks in the skin.

16. PINK ROT

Pink rot (*Cephalothecuim roseum*) is a fungal trouble which may occur in storage.[395] It usually attacks the fruit around the margins of scab lesions. The affected portion becomes firm, corky, dry, and has a bitter taste. In the late stages of its development, the fruiting bodies may give the rot a pink appearance which gives rise to the name pink rot.

Control. One obvious way to reduce losses from pink rot is to store scab-free fruit. Prompt storage at 32°F. (0°C.) will check its growth, but even at this low temperature it may eventually destroy the affected fruits.

[394] R. M. Smock and R. Watson, *Refrig. Eng.*, *42*, 97 (1941).

17. GRAY MOLD

Gray mold (*Botrytis*) is a fungus that may be active in cold storage.[393] It causes a rot which is much like that caused by blue mold, but the affected area is firmer and has a sour taste in contrast to the musty odor and taste of that caused by blue mold. It spreads by contact with normal fruits rather than by a dissemination of spores.

Control. Development of gray mold is greatly delayed by prompt storage at a temperature of 32°F. (0°C.). However, even in cold storage, affected apples will finally become completely unmarketable.

18. FREEZING INJURY

The temperatures at which apples freeze have already been indicated. If the temperature drops below the critical point for very long, characteristic freezing injury will likely appear. Apples that have been slightly frozen have a mealy texture and a slightly alcoholic taste. More severely frozen fruits have a browning of the water-conducting strands or veins in the flesh and develop a breakdown similar to "mealy breakdown." When severely frozen apples are allowed to thaw rapidly, they become brown throughout, soft, and mushy.

Control. Of course, the best procedure is to prevent freezing; but owing to some accident the temperature might fall below the danger point. If cooling goes slightly below the freezing point and the apples are not jarred or moved, no ice crystals may form and no harm may ensue. If ice crystals are actually present in the fruit, the fruit should be left in place and thawed at a temperature of from 40° to 45°F. (4–7 C.) since gradual thawing is less harmful than rapid thawing.[394a] Frozen apples can sometimes be salvaged by slow thawing, but they should be sold immediately since they quickly become mealy.

19. FRUIT SHRIVELING

It has already been pointed out that storing fruit at relative humidities below 85% is likely to result in wilting or shriveling of the skin after prolonged storage. With certain varieties that are not bountifully supplied with natural wax, relative humidities higher than 85% may be required.

Control. Shriveling may be entirely prevented by use of high relative humidities, but surface-growing molds may be a factor. These

[394a] J. M. Lutz, *Proc. Am. Soc. Hort. Sci., 33,* 227 (1935).

molds can usually be satisfactorily controlled by use of ozone. Another means of reducing shriveling in storage is the use of wax emulsions. One advantage of waxing over the use of high humidities is that the mold is not encountered and shriveling is reduced in the poststorage or marketing period as well. On certain varieties, such as Golden Delicious, waxing has commercial possibilities which deserve further test-

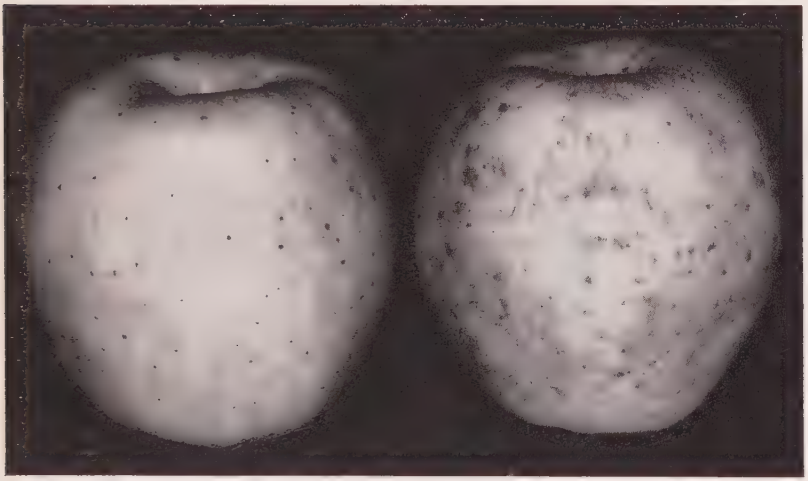


Fig. 62. Left, Golden Delicious apple waxed before storage examined after storage; right, unwaxed Golden Delicious apple showing extreme shriveling examined after storage.

ing (see Fig. 62). The wax emulsions must have been thoroughly tested to indicate possible toxicity to the fruit, its rate of drying, and its effect on the ripening rate of the fruit, as well as its inhibition of the rate of shriveling.

Individual fruits may be wrapped or put in boxes lined with special materials to reduce shrivelling. These materials must be moisture proof to completely prevent shrivelling. On the other hand, if completely moisture proof materials are used and the materials are sealed, there is danger of off flavors in the fruit. On scald susceptible varieties, this disease is often increased by trapping the volatiles around the fruit. If highly impervious materials are used, it is desirable to punch them with numerous holes

20. OFF FLAVORS IN FRUIT

While the development of off flavors in apples is not a fungus or physiological disorder it does come under the category of a storage disorder. One type of off flavor has already been discussed, namely the development of alcoholic characteristics. This trouble develops when the oxygen content of the fruit is too low for normal respiration.

Another general type of off flavor is that caused by absorption of foul odors in the storage room. Certain gases in the storage contribute marked odors to the atmosphere. Apples will absorb these odors rather readily. While they will often lose these odors upon exposure to fresh air after removal from storage, it often requires some little time. More than one lot of apples has been sold at a sacrifice in price because of the strong taste of absorbed odors. The presence of other food products like potatoes, onions, or cabbage often causes contamination of the flavor of the apples. Surface molds or bacteria may contribute a musty odor to the atmosphere which is in turn absorbed by the apples. Certain types of wood like yellow pine in the containers or the wooden siding of the storage room are sometimes a source of odor. Apples absorb these pine odors very readily.

If other food products are the source of odor contamination the solution to the problem would be to store such products separately. Of course, the time factor is involved in the mixed storage of products like potatoes and apples. The longer they are in storage together the more pronounced is the problem. Short periods of storage may not result in any cross contamination.

If surface molds are the source of musty odors in the storage chamber, the problem may be cared for by control of the molds. The control of these molds by various means has been discussed on page 238. It is sometimes claimed that ozone will remove foul odors in the storage chamber. It has been found by actual experiment that if molds are the source of odor contamination, the prevention of mold growth by the use of ozone does result in a lessened odor problem.[394] However, ozone does not remove certain other types of odors like that of pine wood particularly when the storage humidity is high.[395] Odors resulting from certain esters or essential oils are not removed by ozone.[395]

[395] C. R. Gross and R. M. Smock, *Refrig. Eng., 50,* 535 (1945).

Pine wood odors and those from other sources such as from certain esters and essential oils can be removed from the storage atmosphere by means of air purification with activated carbon.[395] The technique of air purification by means of activated carbon is similar to that described in the control of apple scald on page 221.

21. OTHER STORAGE TROUBLES OF THE APPLE

A number of other troubles that occur in the storage are primarily orchard troubles. As a rule control measures lie in orchard procedures.

If apples go into storage with pin-point scab (*Venturia inaequalis*) infections, scab lesions may become larger in storage, particularly if the relative humidity is high.

Spongy dry rot (*Volutella fructi*) is a disease which starts in the orchard and causes sunken rotten areas in the fruit. The fruit surface may become roughened by pustules of fruiting bodies. Its appearance is delayed by storage at low temperatures.

Black rot (*Physalospora malorum*) is an orchard disease that causes a very black discolored rotted area in fruits in storage. The rotted regions usually have a marked zoned appearance.

Brown rot (*Sclerotinia cinerea*) resembles black rot but has a more velvety appearance. Its development is somewhat checked by storage at low temperatures.

Bitter rot (*Glomerella cingulata*) is typified by a brown or black slightly sunken, rotten area. Numerous small black pustules can usually be seen just beneath the skin or just breaking through it. They are arranged in a circle and usually have pink fruiting bodies at their tips. Another type of bitter rot which may appear more commonly in storage is one which may cause red or purple spots or specks with a dark center at picking time.

Bull's eye rot (caused by six possible fungi) is characterized by light brown discolorations, with the center of the rot lighter in color than the margin, giving a bull's eye effect. The surface of the rot is depressed and the flesh beneath is dry and leathery.

Water core is a nonparasitic trouble that affects such varieties as Northern Spy, Rhode Island Greening, Delicious, and Tompkins King. It is characterized by a glassy water-soaked appearance. It is especially severe in regions or seasons of intense sunlight and high tem-

peratures. The disease does not develop in storage, but is essentially an orchard disorder. Mild cases of water core may disappear upon continued storage, but severely affected fruits break down rather quickly in storage. There is no known control.

CHAPTER X

GENERAL CONSIDERATION OF APPLE PRODUCTS MANUFACTURE

A. Introduction

1. DEVELOPMENT OF APPLE PROCESSING IN AMERICA

The apple processing industry of the United States and Canada is an outgrowth of the localization and concentration of the apple growing areas that occurred during the latter part of the nineteenth and early part of the twentieth centuries. Prior to this time apple processing was limited to the home and small farm preparation of such products as fresh and fermented cider, boiled cider, vinegar, jelly, butter, and dried apples. Considerable quantities of fruit were also used in the preparation of sauce and pies.

With the development of intensive orchard areas, large quantities of apples unsuitable for the fresh market because of blemishes, size, color, or other defects became available for processing at relatively low cost. Large-scale commercial manufacture of apple products was made possible by this concentrated source of low cost fruit. In most cases the processing industries resulted from the application of commercial production methods to the preparation, preservation, packaging, and marketing of products previously developed in the home.

Besides the problem of disposing of large quantities of low grade fruit found seasonally in the major apple producing areas, problems of surplus fruit during years of high production have given apple producers concern. Because of seasonal variations in yield and also in consumer purchasing power it has not always been possible for the grower to realize a profit on this crop. Market fluctuations become particularly serious in areas specializing in the production of high quality fruit under costly practices of culture, spraying, storing, and marketing. In recent years efforts have been intensified to develop new industrial uses for agricultural wastes and crops that are subject to surpluses in an attempt to stabilize agricultural markets. Among other crops apples have been studied on this basis.

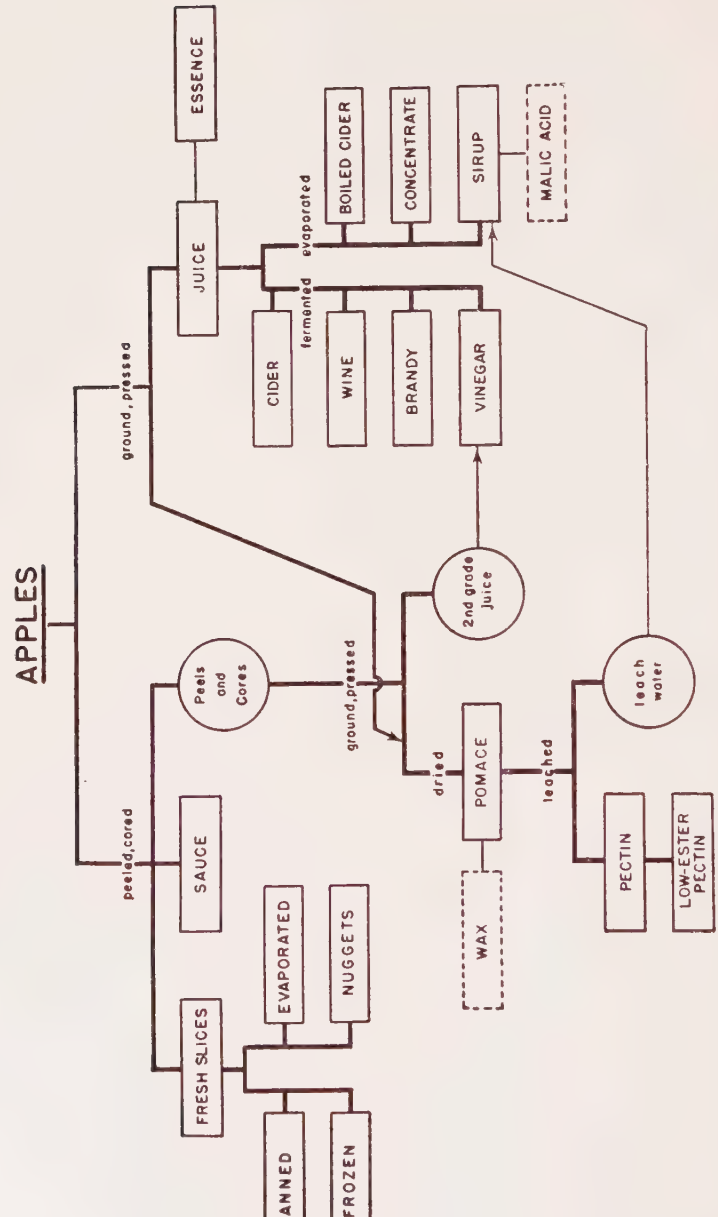


Fig. 63. Twenty primary products of apples.[3109a] Those in dotted rectangles are not in commercial production.

At the present time (1950) apple processing is primarily a food industry. The relatively high cost of producing apples, when compared with certain other agricultural crops such as cereals, legumes, and tubers, and the composition of the fruit itself, makes this crop unpromising as a source of raw material for nonfood industries under a normal economy. As would be expected, the apple processing industries are for the most part located in the concentrated apple growing areas. In the United States the quantities of apples processed annually during the period from 1934 to 1944 inclusive varied between twenty and thirty-five million bushels, representing from 19 to 30% of the total commercial crop.[396] Slightly over half of this fruit was used in preparing canned, dried, and frozen apples. The remainder was used in the manufacture of apple juice, vinegar, fermented beverages, and miscellaneous food products. Among foreign countries only Canada produces appreciable quantities of dried and canned apples though the production of dried apples in Australia, Union of South Africa, and New Zealand is increasing. Apple juice is becoming an important outlet for apples in Canada, England, and European countries, particularly Germany.

2. APPLE PROCESSING IN OTHER COUNTRIES

On a world-wide basis the production of fermented cider far exceeds that of any other apple product. Unlike the apple processing industries of the United States and Canada, which are based on the utilization of fruit surplus to the fresh market, cider production is dependent on fruit grown primarily for this purpose and consists of varieties unsuited for fresh market use. In France, where apple production approaches that of the United States, it is estimated that 95% of the crop is of cider varieties.[397] In Germany, the Soviet Union, Poland, and Switzerland, which are among the next most important apple producers, cider fruit also accounts for a relatively large proportion of the total output, while Rumania, Czechoslovakia, Yugoslavia, Austria, England, and Italy all produce substantial quantities of cider fruit. Beside fermented cider these countries also

[396] *Agricultural Statistics, U. S. D. A.*, 1945, p. 148.

[396a] Adapted from C. H. Hills and J. J. Willaman, *J. New Hampshire Hort. Soc., 10,* 45 (1947).

[397] Imperial Economic Committee, *Apples and Pears. A Survey of Production and Trade in British Empire and Foreign Countries.* H. M. Stationery Office, London, 1938.

produce smaller quantities of apple juice, butter, and juice concentrates. In contrast to the United States the apple processing industries of these countries are usually scattered, small-scale operations; and in many cases the products do not leave the farm.

B. Chemical Constituents Affecting Products Manufacture

1. PROXIMATE COMPOSITION

The technology of apple products can best be studied by giving careful consideration to the composition and physical form of the fruit. The components present and their relation to each other determine not only the industrial possibilities of the crop but also its limitations. The chemical constituents will be discussed here from the

TABLE 28. PROXIMATE COMPOSITION OF EDIBLE PORTION OF APPLE[398]

Constituent	Composition, %
Water	84.1
Carbohydrates	14.9
Sugars	11.1
Fiber	1.0
Acids (as malic)	0.47
Protein	0.3
Ash	0.29
Fat	0.4

standpoint of processing only and reference should be made to previous chapters for more detailed information. Although apples vary somewhat in composition, the proximate values presented in Table 28 suffice to show the materials with which the apple technologist works.

2. WATER

On the basis of quantity present, water is the main constituent of apples. Although it must be admitted that apples would lack much of their appeal as a food without their high water content, nevertheless its presence in the quantities found imposes severe limitations to the industrial use of this fruit. In the manufacture of nonfood products water must be considered as a diluent which increases the cost

[398] C. Chatfield and G. Adams, *U. S. D. A. Circ.*, 549, 1940.

of handling and processing. Its presence makes the fruit subject to decomposition by microorganisms and enzymes so that the crop must be processed during a relatively short season unless expensive refrigerated storage or other means of preservation are used. It is not surprising, therefore, that we find most of the products prepared from apples depending for their value upon a combination of properties that make them characteristically apple in nature. Even when such industrial products as ethyl alcohol and acetic acid are prepared from apples they possess an additional value if they retain the flavors and solids contributed by the apple, as in fermented cider, brandy, and vinegar.

The canning and freezing industries preserve apples for food use in the presence of water, while in drying water content is reduced to a point where decomposition is prevented or delayed. In the latter process water is returned to the products before they are consumed. Controlled fermentations are applied to apple juice to produce somewhat more stable fermented cider, wine, and vinegar, but here again precautions must be taken if undesirable changes are to be prevented during storage. When juice is concentrated or when sugar is added as in the preparations of sirups, jellies, and jams, the water content is reduced so that preservation is realized almost as effectively as by drying. Chemical preservatives may be added to apple products of high water content to prevent or delay decomposition.

Effect of Water Content on Quality and Yield. Differences in water content between varieties of apples and between apples of the same variety grown under varying cultural conditions (Chapter V), account for some of the differences in adaptability of fruits for processing use. When apples are dried important variations in yield are experienced as a result of differences in initial water contents. For example, 100 pounds of raw fruit containing 83% water would yield about the same quantity of dried apples as 113 pounds of fruit containing 85% water or 131 pounds of fruit containing 87% water, other factors being the same. Similar effects on yield are obtained in the production of concentrated apple juice. In the production of fermented cider and wine, water content of the raw fruit determines to a certain extent the alcoholic content of the product, and in the case of brandy and alcohol the proof yield obtained. Difficulties in the manufacture of vinegar of standard strength may occur when apples of high water content are used.

3. CARBOHYDRATES

Carbohydrates are apparently the only class of chemical compounds present in apples in sufficient quantities to be of interest industrially for the manufacture of nonfood products. Carbohydrates are used by the chemical industry as a raw material in the manufacture of alcohols, aldehydes, acids, and a variety of derived products. Nutritionally they are one of the most important sources of energy, and the principal forms found in apples are readily available to man. The carbohydrates found in apples consist of sugars, dextrins, starch, hemicelluloses, pectic substances, and cellulose (Chapter V).

Sugars. The sugars are the main carbohydrates in apples, having an average value of 11.1% of the fruit or about three fourths of the total carbohydrate fraction. Variations in sugar content between varieties and between fruits grown under different cultural conditions markedly affect the value of the fruit for product utilization. Water and the sugars together comprise over 95% of the total constituents in apples and differences in water content therefore have a considerable effect on the concentration of the sugars. In the preparation of products which utilize sugars, such as the alcoholic beverages and vinegar, the processor thinks in terms of low sugar rather than high water content.

Of the sugars *levulose* (D-fructose) predominates, comprising about one half to three fourths of the sugars present.[399] Fructose is the least stable of the commonly occurring sugars and is readily decomposed by heat and certain chemicals so that precautions must be observed in processing if the natural fresh apple flavor is to be preserved. *Sucrose* and *glucose* are present in apples in variable ratios, and with fructose make up the total sugars. The relative sweetness of sugars and their effect on the taste sense has become a rather complicated study[400] but it is safe to assume that the sugars in apples account in large part for the pleasing flavor and therefore the popularity of apples and their products.

D-*Sorbitol.* Apples have been found to contain appreciable amounts of D-sorbitol, which is a reduced form of D-fructose,[401] and

[399] J. R. Eoff, Jr., *Ind. Eng. Chem., 9,* 587 (1917). D. I. Evans, *Ann. Botany, 42,* 1 (1928). R. V. Lott, *Proc. Am. Soc. Hort. Sci., 43,* 56 (1943).

[400] A. T. Cameron, *Sugar Research Foundation, N. Y., Sci. Rept. Ser., No. 9* (1947).

apple juice was at one time suggested as a source of this compound. Its presence in apples is unique among fruits and has been made the basis of a method for detecting the presence of cider in wines.[402] This nonreducing, hexahydric alcohol may account in part for differences found in the soluble solids of juice as determined by specific gravity as compared with its content of sugars, acid, and salts.[403]

Dextrins and Starch. Ripe apples contain little or no *dextrins* or *starch* (Chapter VI). When present, these substances complicate the clarification of juice and juice products and may become an undesirable impurity in the commercial preparation of pectin. The processor is concerned with the removal of these materials from such products by means of diastatic enzymes, clarification treatments, or filtration, in order to increase the clarity of the final products (see Chapters XII, pages 332–347, XIII, pages 391–397, XIV, page 428, and XV, pages 446–448.

Hemicellulose. The hemicellulose fraction has not been studied in detail in relation to processing; it is known that these substances are hydrophilic colloids and as such contribute to the cloudiness of juice and increase the difficulty of clarification and filtration when clear products are desired. Together with cellulose and pectic substances they contribute to the texture and water retaining capacity of such products as canned, dried, and frozen apples, apple sauce, and apple butter.

Cellulose. Cellulose, which constitutes about 1% of the apple on a fresh weight basis, is of importance in apple processing only because of its contribution to the texture and firmness of the flesh (see Chapter V). Cellulose appears to contribute to the firmness and texture mainly through its association with pectic substances in the structure of the cell walls.

Pectic Substances. The pectic substances present in apples have been defined (Chapter V), and changes in these fractions during growth, ripening, and storage and the relation of these changes to texture and firmness of the fruit have been discussed (Chapters V

[401] F. Tutin, *Biochem. J., 19,* 416 (1925). H. H. Strain, *J. Am. Chem. Soc., 59,* 2264 (1937).

[402] J. Werder, *Z. Untersuch. Lebensm., 58,* 123 (1929); *Chem. Abstracts, 24,* 1699. G. Reif, *Z. Untersuch. Lebensm., 59,* 99 (1930); *Chem. Abstracts,* 24, 4892.

[403] H. K. Archbold, *Ann. Botany, 42,* 29 (1928).

and VI). The same considerations of firmness and texture previously discussed on the basis of fresh fruit quality apply to those apple products in which fruit texture is a factor of quality such as in dried, canned, and frozen apples, applesauce and apple butter. Differences in the pectic fractions and in other factors related to texture and firmness, such as cell size and the size and shape of intercellular spaces, account for some of the differences in the suitability for processing purposes found among apple varieties.

The soluble pectic substances in apples are pressed out in the manufacture of juice and contribute viscosity to juice products. The removal or hydrolysis of this pectic material is necessary if gel formation is to be avoided in concentrated juice. Pectin decomposing enzymes have been found among the most effective agents for clarifying apple juice and juice products (pages 333–335).

Besides their important contributions to the quality of various apple products, the pectic substances in apples have value as commercial compounds separate from their value in association with the other constituents of apples. Commercial pectin, used in the preparation of food products such as jams and jellies and for medicinal and other uses, is manufactured to a considerable extent from apples, usually as a secondary by-product prepared from pomace or peels and cores salvaged from the preparation of other products.

Collective Properties of Carbohydrates. Collectively the combination of carbohydrates found in apples possesses properties that are important considerations in the by-product utilization of apples. Apple products of reduced moisture content are highly hygroscopic. These hygroscopic properties are believed to result not only from the sugars but also from the character and amount of hydrophilic colloids present.[404] Apples dried to a moisture content of 24% are in approximate equilibrium with air of 75% relative humidity at 86°F., and when in equilibrium with air of 19% relative humidity contain about 4% moisture. This property presents special problems in drying, packaging, and storing of apple products of low moisture content. It is necessary to evaporate such products under vacuum if the deleterious effect of the high temperatures required to remove residual water is to be avoided. Unless packaged in hermetically sealed containers or stored under conditions of very low humidity these

[404] C. W. Culpepper and J. S. Caldwell, *J. Agr. Research, 35,* 889 (1927).

products will absorb water. The principal problem in the marketing of powdered apples or apple flour is caused by this hygroscopicity which causes these products to cake when opened to moist air.

The hygroscopic properties of the carbohydrates in apples are employed to condition other products. It has been reported that bread containing appreciable amounts of apple products does not dry out as rapidly as bread prepared without apples. By using apples in making bread it has been found possible to extend flour by 15.28%.[405] During the recent war a sirup prepared from apples was used as a substitute for glycerin to retain moisture in certain products. Its principal use was in the tobacco industry where it prevented tobacco products from drying out too rapidly. The presence of fructose and the hydrophilic colloids in apple makes recovery of the sugars in a pure, crystalline form impractical. Therefore, industries using the carbohydrates in apples must confine their usage to products that can employ these sugars as a mixture.

An interesting study of the carbohydrates in powdered apples[406] showed this product to contain 2.5% lignin, 3.0% cellulose, 2.5% hemicellulose, and 5.0% pectin. Both the pectin and hemicellulose fractions liberated carbon dioxide on digestion with hydrochloric acid; 37.5% of the carbon dioxide liberated was contributed by pectin, 35.7% by sugars, 12.5% by hemicellulose, and 14.3% by unidentified alcohol-soluble material.

4. ACIDS

The acid content of apples is an important consideration in by-product manufacture (see Chapter V). Apple products intended for culinary use such as dried, canned, or frozen apples and applesauce, should be prepared from fruit of higher acid content than is desired in dessert fruit. The acid content of the fresh fruit is of particular importance in the manufacture of apple juice as the natural flavor of juice is not altered by the addition of sugar. In the preparation of apple juice and juice products the manufacturer usually resorts to blending of varieties of different acid content in order to obtain a uniform product of the desired acidity. The possibility of recovering

[405] H. Mohorcic, *Graz. Arch. Hyg., 88,* 56 (1918); *Chem. Abstracts, 13,* 2939.
[406] I. A. Manville, F. J. Reithel, and P. M. Yamada, *Food Research, 4,* (1), 47 (1939).

malic acid as a by product during the manufacture of apple sirup has been investigated.[407]

5. NITROGEN COMPOUNDS

The technology of nitrogen compounds in apple products has received little attention because of the limited quantities present (see Chapter V). Although reports indicate that protein fractions contribute to the clarification problem in juice, and enzyme preparations with proteolytic activity have been suggested as clarifying agents,[108] the use of pectin-hydrolyzing enzyme preparations has proven more practical. The low nitrogen content of apples makes enrichment of the juice with nitrogen compounds distinctly advantageous in fermentation processes.

A protein fraction, containing 8.5% nitrogen, has been isolated from the flesh of Baldwin apples.[408a] Amino nitrogen amounted to 93.5% of the total nitrogen of the isolated protein, and the 15 amino acids for which values could be obtained accounted for 86.3% of this amount. The low nitrogen content was attributed to the presence of a phlobaphene or very similar tannin-like compound which could not be separated without some degradation of the nitrogenous portion and which imparted a red-brown color to the preparations. Typical oxidase reactions were exhibited by portions of the isolated protein complex and the presence of nucleoprotein was indicated.

6. MINERAL CONSTITUENTS

Information on the influence mineral constituents play in apple product manufacture is meager, and it appears that their principal role is in the nutritional value of the products (see Chapter V). The use of apple pomace[409] and peel waste[410] for fertilizer has been sug-

[407] V. L. S. Charley, D. P. Hopkins, and A. Pollard, *Fruit Products J., 22,* (4) 108 (1942); *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1941,* 96. R. E. Buck and H. H. Mottern, *Ind. Eng. Chem., 39,* 1087 (1947).

[408] S. A. Waksman, *Canner, 54,* (18), 45 (1922). M. L. Daughters, *Canning Age, 8,* 503 (1927).

[408a] S. G. Davis, C. R. Fellers, and W. B. Esselen, Jr., *Food Research, 14,* 417 (1949).

[409] B. T. B. Baker and C. T. Gimingham, *J. Board Agr., 22,* 851 (1915); *J. Soc. Chem. Ind., 35,* 135 (1916); *Chem. Abstracts, 10,* 2273.

[410] P. E. Browning, *Ind. Eng. Chem., 9,* 1043 (1917).

gested because of the relatively high content of potassium and phosphorus. These wastes have been found impractical for such use, however, because of their deleterious action on the soil, presumably because of the acids present.

7. FATS AND OILS

The fats in apple tissues have received little attention because the amount present is small and unimportant in the nutritional value of this fruit or in processing.

Apple Seed Oil. Apple seeds are comparatively rich in oil and investigations of their use as a source of this staple have been prompted by scarcities of fats, particularly in European countries during times of war.[411] [415] Properties and constants reported for apple seed oil are presented in Table 29. Metals present in the seeds of apples have also been investigated.[416] Seeds were separated into brown outer case, thin translucent coat of the endosperm, and endosperm for analysis. The limited quantity of apple seeds available and difficulties in their recovery make their use as a source of oil impractical under normal conditions.[417]

8. WAXES

The waxlike constituents found on the surface of the apple have been discussed (Chapter V, page 73). Problems in the recovery of these substances and the limited quantities available in apples make this fruit an unpromising source of these compounds. At present they are of no commercial importance although the use of ursolic acid in paints and varnishes[418] and in certain other products has been investigated.

[411] N. & H., *Z. angew. Chem., 29,* I, 337 (1916).
[412] P. Huber, *Landw. Vers. Sta., 75,* 443 (1911).
[413] A. Truelle, *Vie. Agr. et rurale, 9,* 101 (1919); *Expt. Sta. Record, 40,* 511 (1919).
[414] A. Truelle, *Compt. rend. acad. agr. France, 12,* 81 (1926); *Chem. Abstracts, 20,* 2590.
[415] G. Bertrand, *Compt. rend. acad. agr. France, 1942,* 544; *Chem. Zentr., 1943, II,* 1510; *Chem. Abstracts, 38,* 6119.
[416] H. Ramage, *Nature, 137,* 67 (1916).
[417] N. & H., *Z. angew. Chem., 29,* I, 337 (1916).
[418] H. A. Gardner, G. G. Sward, and A. W. Van Henckeroth, *Am. Paint Varnish Mfrs. Assoc. Sci. Sect. Circ., 379,* 154 (1931); *Chem. Abstracts, 25,* 3182.

9. VOLATILE OILS AND ESTERS

Of particular interest to apple processors is the volatile, oil-like fraction present in this fruit which is responsible for the aroma and much of the flavor of apples. Because of the importance of this fraction to the flavor of apple products and because it is readily lost by volatilization during heating, numerous efforts have been made to develop methods for recovering it in order to return it to the product

TABLE 29. CONSTANTS OF APPLE SEED OIL

Properties and constants	Pritzker and Jungkung[a]	Petroleum ether extracted oil[b]	Petroleum ether extracted oil[c]	Huber[d]
Oil content of seed, %	18.0	—	22.5	24.03
Protein in seed, %	29.6	—	—	27.05
Moisture in seed, %	6.4	—	—	8.03
Crude fiber of seed, %	13.5	—	—	8.96
Ash content of seed, %	3.42	—	—	3.29
Color of oil	Light yellow	Transparent light yellow	Light yellow	—
Odor	Bitter almond	Agreeable	Slight bitter almond	—
Density	—	0.9097	—	0.9237
$n(25°)$	(40°) 62.9	—	70.55	—
Acid No.	2.3	24	2.9	—
Saponification No.	187.7	178	189.5	—
Iodine No.	(Hanus) 122.4	104	119.8	(Hubl) 121
Ester No.	185.4	154	—	—
Reichert-Meisl No.	0.22	1.17	—	—
Polenske No.	0.4	0.53	—	—
Hehner No.	—	89.70	—	—
Iodine No. of fatty acids	—	115	129.5	—
Saponification No. of fatty acids	—	—	195.5	—
Glycerol, %	—	8.4	—	—

[a] J. Pritzker and R. Jungkunz, *Z. Untersuch. Lebensm., 70,* 255 (1935).
[b] Z. Hokrova, *Casopis Ceskoslov. Lekarnictva, 18,* 137 (1938); *Chem. Abstracts, 32,* 9533.
[c] N. & H., *Z. angew. Chem., 29,* I, 337 (1916).
[d] P. Huber, *Landw. Vers. Sta., 75,* 443 (1911).

or to use it as a flavoring in other products. Synthetic preparations are marketed for the purpose of enhancing the flavor of apple and other products, but the most characteristic flavors are those recovered from the fruit itself (page 369). An analysis of the volatile aromatic fraction of Jonathan apples showed it to consist mainly of amyl esters of formic, acetic, and caproic acids with smaller amounts of caprylic

esters, acetaldehyde, and geraniol.[419,420] In a more recent study of the chemical composition of an essence prepared from the juice of approximately equal parts of McIntosh and Stayman Winesap apples the principal components together with the relative amounts of each class were: alcohols (92%)—methanol, ethyl alcohol, propyl alcohol, 2-propanol, butyl alcohol, isobutyl alcohol, D-2-methyl-1-butanol, and hexyl alcohol: carbonyl compounds (6%)—acetaldehyde, acetone, caproaldehyde, and 2-hexenal: esters (2%)—ethyl butyrate and ethyl caproate. Methanol, ethyl alcohol, 2-propanol, butyl alcohol, and formic, acetic, propionic, butyric, and caproic acids were identified as components of other esters. These compounds were present in the original apple juice at a total concentration of approximately 50 parts per million.[421]

10. ASTRINGENT MATERIALS

Effect on Flavor. The astringent materials present in apples and the role they play in determining the flavor and quality of this fruit have been discussed (Chapter V, page 74). These considerations are of equal importance in processed apple products intended for food use. Very astringent fruit that is not considered suitable for dessert use may be used to advantage in preparing certain products such as jelly, jam, and butter and fresh and fermented apple juice. In the case of jellies and butters the high sugar and acid contents permit a greater proportion of astringent materials, and in fact flavor is enhanced by them. In the manufacture of juice and juice products, particularly fermented cider, the astringent materials are often referred to as contributing *body* and their presence results in a fuller, heavier flavor.

Effect on Color. Equally important with the effect of astringent materials on flavor is their influence on the color of apple products. When apples are cut in preparation for processing the flesh darkens. The chemical reactions involved in this color transformation involve oxidation of *tannins* in the presence of the oxidase enzymes present in the flesh and will be discussed in detail in the section on enzymes. These reactions are responsible for the characteristic color of many apple products such as juice and juice products and apple butter. In preparing products such as dried, canned, and frozen apples and

[419] F. B. Power and V. K. Chesnut, *J. Am. Chem. Soc., 42,* 1509 (1920).
[420] F. B. Power and V. K. Chesnut, *J. Am. Chem. Soc., 44,* 2938 (1922).
[421] J. W. White, Jr., *Food Research, 15,* 68 (1950).

applesauce precautions must be taken and often special treatments are given to delay or prevent these reactions from proceeding in order that the products will retain a light color. The development of dark color is accompanied by a conversion of ascorbic acid to the dehydro form.

Tannins also form a black pigment with iron. To prevent the formation of grey or black pigments which result in an unattractive color, it is necessary that all equipment coming in contact with the apples during processing be constructed of metals that will not contribute iron to the product. In certain products such as fermented apple juice it is possible to remove the black color by special treatments which precipitate the iron or tannin. The tannins in apples may be used in part to clarify juice and juice products. The process depends on the precipitation of colloidally dispersed tannin by gelatin. In this process tannin is usually added to the juice in order that the precipitate be sufficiently voluminous to accomplish complete clarification (Chapter XII, page 336).

11. COLOR COMPOUNDS

The pigments in apples (Chapter V) are of considerable importance in the processing of this fruit. The red pigment found in red-colored varieties has been identified as the anthocyanin *idaein* chloride (*3-β*-galactosidylcyanidin).[422,423] When present in foods canned in tin containers anthocyanin pigments react with dissolved tin to give violet-colored salts and also accelerate the rate of corrosion of the container.[424] The yellow flavonol pigment *3-galactosidylquercetin*,[423] which is considered to occur in all varieties of apples, contributes the typical yellow color to apple products.

12. ENZYMES

Of the various enzymes found in apples (Chapter V), the oxidases are of greatest interest to processors because of their effect on the color and nutritive value of apple products. The action of these enzymes is responsible for the characteristic amber color of apple juice and juice products and for at least part of the dark color of

[422] I. J. Duncan and R. B. Dustman, *J. Am. Chem. Soc., 58,* 1511 (1936).
[423] C. E. Sando, *J. Biol. Chem., 117,* 45 (1937).
[424] C. W. Culpepper and J. S. Caldwell, *J. Agr. Research, 35,* 107 (1927).

apple butter. Their action must be prevented during the preparation and storage of dried, canned, and frozen apples and applesauce if these products are to retain the natural light color of apple flesh. Unless they are inactivated they cause the rapid conversion of ascorbic acid to the dehydro form which is destroyed in later processing. It is of interest to the processor that the greatest oxidase activity of many commercially available varieties has been found in the core and core line,[425] since the most rapid discoloration often takes place around the seed cells after coring.

Control of Discoloration. A number of methods have been proposed for controlling darkening of apple tissue during processing and storage (see Chapter V). In products such as canned apples and canned sauce, heat used in preservation inactivates the enzymes and the only precautions necessary are treatments to delay temporarily discoloration during preparation. Immersion in water to prevent contact with atmospheric oxygen will give protection for short periods, but more satisfactory control is obtained when the cut fruit is immersed in a dilute sodium chloride solution. Sodium chloride and other chloride salts appear to inhibit the oxidizing enzymes without destroying either the peroxide or the enzymes.[426] Alum salts and oxalates exert inhibiting effects but acetates and tartrates have no appreciable effect. Other substances reported as inhibiting browning are sulfhydryl compounds, cysteine and glutathione, including pineapple juice which probably contains glutathione,[427] thiosulfate solutions containing approximately 0.01 to 0.5% thiosulfate,[428] and thiourea solutions.[429] Nitrate salts increase the rate of browning and sulfates have no retarding effect. Hydrochloric acid and sodium sulfite appear to destroy the peroxide in a manner similar to sulfur dioxide.

Ascorbic acid, when present in the reduced form prevents browning but is rapidly oxidized by the enzyme system. It is used to delay darkening in frozen apples (page 307) and its use has been suggested for preparing light colored juice (page 330). The polyphenolase has been found to be more resistant to heat than the peroxidase but the

[425] B. D. Drain, *Proc. Am. Soc. Hort. Sci., 20,* 25 (1923).
[426] E. L. Overholser and W. V. Cruess, *Calif. Agr. Expt. Sta. Tech. Paper, 7,* (1923).
[427] A. K. Balls and W. S. Hale, *Ind. Eng. Chem. 27,* 335 (1935).
[428] E. Elion, U. S. Pat. 2,298,933, Oct. 13 (1942); *Chem. Abstracts, 73,* 1800.
[429] F. E. Denny, U. S. Pat. 2,093,865, Sept. 21 (1937); *Chem. Abstracts, 31,* 8060.

latter was much more difficult to inhibit with chemical agents.[430] Sodium diethyl thiocarbamate completely inhibited polyphenolase in concentrations of 10^{-4} *M* or slightly higher whereas peroxidase remained active. Cysteine hydrochloride exerted a greater inhibiting effect on polyphenolase than on peroxidase.

Of the various agents available, sulfur dioxide is the only one that has proven practical commercially to prevent discoloration of dried apples. Frozen apples are usually treated with ascorbic acid or sulfur dioxide, or they are heated sufficiently to destroy the enzyme system. The continued presence of sulfur dioxide or ascorbic acid is required if browning is to be prevented during storage of the frozen product, and the sulfur dioxide content of dried apples must also be maintained during storage to prevent darkening. Catalase activity, as measured by the rate of decomposition of a dilute hydrogen peroxide solution, is frequently used as an index of the completeness of inactivation of the enzyme system responsible for browning but the use of a catechol test of oxidase activity is coming into more general use and is considered more reliable.[431]

Pectic Enzymes. Changes in the various pectic fractions of fresh apples during ripening and storage have been discussed (Chapters V and VI). Extracts containing small but measurable amounts of pectinase have been prepared from apple pomace.[432] It has been suggested that pectin decomposition may also be accomplished in apple tissue by the action of ascorbic acid or peroxides.[433] These changes in pectic fractions in apples during storage result in changes in the quality of products manufactured from them and losses in the manufacture of commercial pectin (page 445).

13. VITAMINS

The vitamin content of fruits and vegetables and methods for their preservation during handling and processing of these crops have been of particular interest to technologists and processors during recent years. The vitamin content of apples has been discussed in Chapters V and VI. Carotene (provitamin A) is relatively stable to oxidation during canning or freezing and may therefore be expected

[430] J. D. Ponting, *The Enzymic Oxidation of Ascorbic Acid. Thesis,* Univ. Calif., Northern Section, 1944.
[431] J. D. Ponting, *Quick Frozen Foods, 7,* (5), 31 (1944).
[432] C. H. Hills, *private communication.*
[433] Z. I. Kertesz, *Plant Physiol., 18,* 308 (1943).

to be retained in these products to a considerable extent. Values for fresh and canned apples and canned applesauce are given in Table 32. Because of the limited amounts of the B vitamins in apples little work has been done relative to the effect of various processing treatments on their retention. Very little thiamin (vitamin B_1) has been found in dehydrated apples.[434] Values for thiamin, riboflavin, and niacin in fresh and dehydrated apples and canned applesauce are given in Table 32.

Ascorbic Acid (Vitamin C). Apples are not as good a source of ascorbic acid as certain other fruits. Nevertheless, the processor is concerned with retaining as much of this vitamin as possible in the products he prepares so that they may serve to supplement other sources in the diet. Several considerations enter into the problem of retaining the ascorbic acid of apples and apple juice during processing. Although early workers agreed that apples do not contain *ascorbase (ascorbic acid oxidase, ascorbic oxidase, ascorbinase)*[430,435] more recent work[436] has resulted in the isolation of a relatively active preparation of an enzyme from apples capable of oxidizing ascorbic acid directly. As discussed under *enzymes* (page 84) peroxidases and polyphenolases cause its rapid oxidation in the presence of natural phenolic compounds.[430,435] This vitamin is also subject to spontaneous oxidation which is catalyzed by certain metals of which copper is most prominent.

Treatment of fruit during preparation with sulfur dioxide,[437] or immersion in a solution of sodium chloride,[438,439] have been found effective in reducing loss of ascorbic acid. The greater retention of this vitamin in canned fruit that has been immersed in dilute (2%) brine for a period was attributed to the metabolic utilization by the apple tissue of the oxygen in the fruit itself, thus preserving the vitamin from contact with oxygen in later preparation steps. Although dried apples are treated with sulfur dioxide to prevent discoloration

[434] D. G. Heberlein and L. E. Clifcorn, *Ind. Eng. Chem., 36,* 912 (1944).
[435] S. W. Johnson and S. S. Zilva, *Biochem. J., 31,* 438 (1937).
[436] F. M. V. Hackney, *Nature, 158,* 133 (1946).
[437] I. K. Murri, N. P. Onokhova, A. V. Kudryavtzeva, and G. K. Guszevich, *Bull. Applied Botany, Genetics, Plant Breeding Leningrad, Suppl. 67,* 113 (1934); *Chem. Abstracts, 28,* 7317.
[438] E. F. Kohman, W. H. Eddy, and V. Carlsson, *Ind. Eng. Chem., 16,* 1261 (1924).
[439] E. F. Kohman, *Food, 7,* 49 (1937).

this product has generally been found to be a poor source of vitamin C.[440–442] Immersion in a dilute brine is generally practiced in preparing apples for canning and for sauce manufacture, but canned apples and sauce have not been found to retain appreciable amounts of this vitamin.[443–446] Apple jelly has been reported to retain considerable proportions of vitamin C when prepared under favorable conditions for retention of this vitamin.[447] It is unfortunate, from the standpoint of vitamin C content, that many apple products are prepared from peeled fruit because it has been well established that this vitamin is concentrated in the portion removed by peeling.[448–459] Concentration of vitamin C in the red peel has been found to be as much as six times as high as in core material. Green skinned varieties are not as high.

[440] *Food Inds., 16,* 171 (1944).
[441] M. H. Givens, H. B. McClugage, and E. G. Van Horne, *Am. J. Diseases Children, 23,* 215 (1922).
[442] P. F. Eckman, *J. Am. Med. Assoc., 78,* 635 (1922).
[443] E. C. van Leersum and N. P. Hoogenboom, *Nederland. Tijdschr. Geneesk., 74,* II, 5127 (1930); *Chem. Abstracts, 26,* 534.
[444] E. F. Kohman, *Canning Age, 9,* 227 (1928).
[445] C. R. Fellers, P. D. Isham, and G. G. Smith, *Proc. Am. Soc. Hort. Sci., 29,* 93 (1932).
[446] C. R. Fellers, M. M. Cleveland, and J. A. Clague, *J. Agr. Research, 46,* 1039 (1933).
[447] A. Harden and R. Robinson, *J. Army Med. Corps, 32,* 48 (1919).
[448] C. R. Fellers, P. D. Isham, and G. G. Smith, *Proc. Am. Soc. Hort. Sci., 29,* 93 (1932).
[449] S. S. Zilva, F. Kidd, C. West, and E. O. V. Perry, *Dept. Sci. Ind. Research Brit. Rept. Food Invest. Board, 1934,* 164 (1935).
[450] E. N. Todhunter, *Proc. Wash. State Hort. Assoc., 31st Ann. Meeting, 1935,* 43.
[451] O. Fernandez and C. Alfageme, *Rev. sanidad. hig. pub., 11,* 525 (1936); *Chem. Abstracts, 31,* 8056.
[452] E. L. Batchelder and E. L. Overholser, *J. Agr. Research, 53,* 547 (1936).
[453] K. Halacka, *Casopis Ceskoslov. Lekarnictva, 20,* 69 (1940); *Chem. Zentr., 1941, I,* 1102; *Chem. Abstracts, 37,* 474.
[454] O. H. Keys, *New Zealand J. Sci. Technol., 24B,* 146 (1942); *Chem. Abstracts, 38,* 176.
[455] O. H. Keys, *New Zealand Med. J., 40,* 379 (1941); *Chem. Abstracts, 36,* 2944.
[456] E. B. Kidson, *New Zealand J. Sci. Technol., 25B,* 134 (1943); *Chem. Abstracts, 38,* 3377.
[457] T. v. Fellenberg, *Mitt. Gebiete Lebensm. Hyg., 33,* 212 (1942); *Chem. Abstracts, 38,* 4042.
[458] V. B. Fish, *Proc. Am. Soc. Hort. Sci., 43,* 73 (1943).
[459] E. Gross, *Gartenbauwiss., 17,* 500 (1943); *Chem. Zentr., 1943, II,* 2322, *Chem. Abstracts, 38,* 6413.

Freshly prepared apple juice is generally as good a source of this vitamin as is the fruit from which it is prepared and there appears to be little loss during the first 12 hours after pressing.[446,460,461] Apple juice has invariably been found to be a poor source of vitamin C, however, because of serious losses which occur during storage of the fresh juice and in processing.[462–464] As would be expected from the studies reported on the oxidation of ascorbic acid to the dehydro form during the enzymic darkening of apples, vitamin C in fresh apple juice has been found to exist in the reversibly oxidized form, and deaeration or the use of antioxidants has no beneficial effect on its retention during processing and storage.[465] Flash pasteurizing at 170° F. under commercial conditions inactivated the oxidases but these enzymes were still active at 165° F. After heating, about 70% of the vitamin C was found to be destroyed.[466] Preliminary reduction of vitamin C results in preservation of 64 to 92% after heating. Fermentation greatly reduces the ascorbic acid content of juice.[467]

Vitamin Fortification. Studies on the retention of added ascorbic acid in apple juice[468] and canned apples and jelly[469,470] have shown storage losses to be small and indicate that no difficulty would be encountered in enriching these products in order to make them good sources of this vitamin. The practice of fortifying commercial apple products with ascorbic acid is becoming increasingly important and has a beneficial effect on color as well as the nutritional value of

[460] V. L. S. Charley, *Food Manuf., 16,* 102 (1941).
[461] W. Zimmermann, L. Matsch, and R. Weber, *Vorratspflege u. Lebensmittelforsch., 3,* 1 (1940); *Chem. Zentr., 1940, I,* 3333; *Chem. Abstracts, 36,* 4211.
[462] B. C. Collier, M. F. M. Morrison, and M. E. Morse, *Proc. Nova Scotian Inst. Sci., 20,* 121 (1940–41).
[463] C. C. Strachan, *Can. Dept. Agr. Tech. Bull.,* 40, (1942); *Chem. Abstracts, 36,* 4619.
[464] J. Reschke, *Ernährung, 8,* 137 (1943); *Chem Zentr., 1943, II,* 1761; *Chem. Abstracts, 38,* 5996.
[465] C. C. Strachan, *Can. Dept. Agr. Tech. Bull.,* 40, 1942; *Chem. Abstracts 36,* 4619.
[466] M. M. Eidel'man, *J. Physiol. U.S.S.R., 22,* 682 (1937); *Chem. Abstracts, 32,* 9195.
[467] J. Tavernier and P. Jacquin, *Bull. assoc. chim., 63,* 111 (1946); *Chem. Abstracts, 41,* 1048.
[468] F. B. Johnston, *Fruit Products J., 22,* 195 (1943).
[469] S. S. Zilva, T. N. Morris, and E. O. V. Perry, *Dept. Sci. Ind. Research Brit., Rept. Food Invest. Board, 1934,* 203 (1935).
[470] S. S. Zilva and T. N. Morris, *ibid., 1936,* 210 (1937).

the product (page 348). Fortification of apple juice to give a product containing at least 30 mg. % vitamin C is required by the Canadian government. Studies on the retention of added vitamin A to apple juice concentrate (solid) have shown negligible loss of the vitamin over prolonged periods of storage at 32°F., and only slight losses at room temperature (73°F.). Losses at higher temperatures were considerable.[471]

14. INTERNAL ATMOSPHERE OF APPLES

Of particular interest in the canning of apples are the gases contained in the intercellular spaces of the fruit (see Chapter VI). Apples have been reported to contain from 12 to 29% gases by volume.[472–474] As a result of respiration occurring in the apple itself these gases contain a higher proportion of carbon dioxide than is found in normal atmosphere. It has also been found that the ratio of carbon dioxide to oxygen varies greatly with the temperature of storage of the fruit, being considerably lower at low storage temperatures (Table 30).[475]

TABLE 30. ANALYSES OF GAS IN INTERCELLULAR SPACES OF YELLOW NEWTOWN APPLES[475]

Temp. of storage, °F.	No. of determinations	CO_2, %	O_2, %	CO_2 plus O_2, %	N_2 (by difference), %
36	5	6.7	14.2	20.9	79.1
43	30	8.4	12.9	21.3	78.7
52	27	12.2	10.7	22.9	77.1
68	31	17.2	5.5	22.7	77.3
86	29	21.4	3.2	24.6	75.4

When apples are sealed in tin containers while retaining their normal content of oxygen, serious can corrosion results and after a relatively short period pinholes will develop with resultant loss of product. This oxygen also exerts a deleterious action on the quality

[471] M. N. Moyer, *Food Research, 11,* 516 (1946).
[472] J. R. Magness, *Botan. Gaz., 70,* 308 (1920).
[473] B. S. Clark, *Canning Age,* February (1923). Reference and data taken from A. W. Bitting, *Appertizing; or, The Art of Canning,* The Trade Pressroom, San Francisco, 1937, p. 131.
[474] C. W. Culpepper and H. H. Moon, *Canner, 68* (8), 21 (1929).
[475] J. R. Magness, *Botan. Gaz., 70,* 308 (1920).

of the fruit itself. Several procedures have been developed to reduce the oxygen content of apples before sealing in tin containers (page 296). Variations in the effectiveness of these procedures may be caused by differences in the temperature at which fruit is stored before processing, as well as by variations in gas content found among different varieties.

C. Nutritional Value of Apples and Apple Products

1. PROXIMATE COMPOSITION

The nutritive value of apples and apple products can best be evaluated on the basis of their chemical composition. Table 31 presents the proximate composition of apples and a number of apple products. Available data on vitamin and mineral constituents are presented in Table 32. Values expressed in these tables are averages and consideration must be given to variations in composition according to variety and other factors.

The principal food value of apples is in their content of carbohydrates. As has been previously stated (page 250) about 75% of the carbohydrates consists of sugars that are readily assimilated by man. Apples are considered a food of moderate energy value, comparable in this respect to many other fruits. Most apple products are either comparable to fresh apples in energy value or higher because of concentration or the addition of sugar during processing.

Although apples do not rank high as a source of minerals or vitamins, their use in the diet supplements other sources of these nutrients. In common with most other fruits, apples are relatively low in protein and fat. These nutrients are contained in comparable amounts in the various apple products with the exception of the vitamins.

2. APPLES AND APPLE PRODUCTS IN HUMAN PHYSIOLOGY

Legend has served to emphasize the importance of apples from the standpoint of health. "An apple a day keeps the doctor away," is one of several old rhymes that have tended to focus man's attention on the importance of apples in the diet to his well being. It is certain that the eye appeal and appetizing qualities of apples have an important nutritional function.

Numerous studies have been made on the use of apples and

TABLE 31. PROXIMATE COMPOSITION OF APPLES AND APPLE PRODUCTS[a]

Product	Water, %	Protein, %	Fat, %	Ash, %	Carbohydrates			Acid as malic, %	Fuel value per 100 grams, calories
					Total, %	Fiber, %	Sugars, %		
Fresh apples (edible portion)	84.1	0.3	0.4	0.29	14.9	1.0	11.1	0.47	64
Canned applesauce, unsweetened	88.4	0.2	0.2	0.3	10.9	0.6	7.9	0.3	46
Canned applesauce, juice pack	87.3	0.2	0.2	0.3	12.0	0.6	—	—	51
Canned applesauce, sweetened	79.8	0.2	0.1	0.2	19.7	0.6	17.6	0.4	80
Dried apples (common)	23.	1.4	1.0	1.4	73.2	4.6	54.0	2.3	307
Dried apples (low moisture)	1.6[b]	1.4[b]	1.0[b]	2.0[b]	90.1[b]	3.8[b]	—	—	375
Apple juice	87.1	0.1	0.0	0.25	12.5	—	10.5	0.52	50

[a] C. Chatfield and G. Adams, *U. S. D. A. Circ.*, 549, 1940.
[b] P. L. Pavcek and the Committee on Food Composition, *Ind. Eng. Chem., 38,* 583 (1946); average values presented.

TABLE 32. VITAMIN AND MINERAL CONSTITUENTS IN APPLES AND APPLE PRODUCTS

Milligrams per 100 grams

Products	Ca	P	Fe	Carotene	Ascorbic acid	Thiamin	Riboflavin	Niacin
Fresh apples (edible portion)[b]	6	10	0.3	90[e]	5	0.04	0.02	0.2
Dried apples (low moisture)[a]	24	42	4.1	—	9	0.02	0.04	0.5
Dried apples (low moisture)[b]	24	42	4.1	—	11	0.05	0.08	0.5
Canned applesauce[b]	4[d]	6[d]	0.2[d]	60[e]	1	0.01	0.01	Trace
Applesauce, canned in tin[c]	—	—	—	—	0.8	—	—	—
Applesauce, canned in glass[c]	—	—	—	—	0	—	—	—
Frozen apples[c]	—	—	—	36[e]	—	—	—	—
Apple juice, canned in tin[c]	—	—	—	—	0.5	—	—	—
Apple juice, canned in glass[c]	—	—	—	—	0.8	—	—	—

[a] P. L. Pavcek and the Committee on Food Composition, *Ind. Eng. Chem., 38,* 853 (1946); average values presented.
[b] From *Tables of Food Composition in Terms of Eleven Nutrients, U. S. D. A. Misc. Pub.*, 572, 1945.
[c] L. E. Booker, E. R. Hartzler, and E. M. Hewston, *U. S. D. A. Circ.*, 638, 1942.
[d] Imputed values.
[e] As international units, Vitamin A value, calculated from carotene or including carotene analysis.

apple products in maintaining healthy digestive systems and in the treatment of gastrointestinal disturbances. It is not possible to discuss here in detail the various aspects of this somewhat controversial subject and the reader is therefore referred to summaries of these studies appearing in the literature.[476 479,479a] Apples have been recognized by the American Medical Association's Council on Foods as a useful therapeutic agent in the dietary management of diarrhea.[479b] This therapeutic value has been attributed to their pectin content.[479a] Concentrated apple juice, concentrated apple sirup, dehydrated apple powder, and vinegar have been recommended to reduce curd tension of milk used in infant feeding. Recent studies indicate that concentrated apple juice, in addition to its value in lowering the curd tension and *p*H of milk, has the advantages of palatability, ease of use, and increased nutritive value resulting from the presence of fruit sugars.[480]

D. Governmental Regulations Affecting Apple Products

Apple processing is primarily a food industry and in common with other food industries has a profound effect on individual and national health. In order to protect the consumer from adulteration and dangerous food products most governments have established laws regulating the production and marketing of foods with which apple products must comply. In the United States the Food and Drug Administration, under the Federal Food, Drug, and Cosmetic law, is charged with the task of prohibiting the movement in interstate commerce of adulterated and misbranded foods.

1. ADULTERATION

Among other considerations a food is deemed adulterated under this act if[481]: (*1*) it contains any poisonous or deleterious substance

[476] V. L. S. Charley and T. H. J. Harrison, *Imp. Bur. Hort. Plantation Crops, East Malling, Kent, Tech. Commun., No. 11,* 14 (1938).
[477] I. A. Manville, *41st Ann. Conv. Intern. Apple Assoc.,* Boston Mass., 1936.
[478] I. A. Manville, *The Apple in Ancient and Modern Nutrition.* Oregon Medical School, Portland, Ore.
[479] Anonymous, *A Digest of Scientific Literature Concerning the Apple.* Wash. State Apple Advertising Commission, 1938.
[479a] G. H. Joseph, *Bull. Natl. Formulary Comm., 9.* 2 (1940).
[479b] Am. Med. Assoc. Council on Food, *Accepted Foods and their Nutritional Significance.* Am. Med. Assoc., Chicago, 1939.
[480] C. C. Flora and C. W. Holdaway, *Va. Agr. Expt. Sta. Bull., 110,* (1948).
[481] *Service and Regulatory Announcements.* Federal Security Agency, Food, Drug and Cosmetic, No. 1, Rev. 1, 1944.

which may render it injurious to health; (2) if it contains any added poisonous or added deleterious substance which is required in the production thereof and which cannot be avoided by good manufacturing practice, when such substances are present in the finished product in excess of limits fixed as necessary for the protection of health; (3) if it consists in whole or in part of any filthy, putrid, or decomposed substance, or is otherwise unfit for food; (4) if it has been prepared, packed, or held under insanitary conditions whereby it may have been contaminated with filth, or whereby it may have been rendered injurious to health; or (5) if the container used in packaging it contains any poisonous or deleterious substance which may render the contents injurious to health. Other provisions of adulteration regulate the use of coloring matter, the removal, omission, or substitution of valuable constituents, and the concealment of damage or inferiority of the product.

2. LABELING

A food is deemed to be misbranded under the United States Food, Drug, and Cosmetic Act if its label is false or misleading in any particular. Among the many considerations involved in labeling are included the proper identification of the contents, fill and shape of the container, use of imitation ingredients, and the identity and place of business of the manufacturer, packer, or distributor. A food for which standards of identity have been prescribed by regulations must conform to such definition and standard or so specify on its label. Legal definitions and standards of identity for apple products so far (1949) promulgated are limited to jams, jellies, and butter.[482] These standards are discussed in greater detail in Chapter XIV.

If the product purports to be for special dietary uses its label must bear such information concerning its vitamin, mineral, and other dietary properties as the administration determines to be necessary in order fully to inform purchasers as to its value for such uses. The use of any artificial flavoring, artificial coloring, or chemical preservative must be indicated on the label with certain specific exemptions such as the use of artificial color in some dairy products.

In conforming to these regulations it is necessary for processors of apples to employ good commercial practice and operate their estab-

[482] *Definitions and Standards for Food.* Federal Security Agency, Service and Regulatory Announcements, Food, Drug and Cosmetic, No. 2, 1944.

lishments with due regard for the principles of good housekeeping. Special attention must be given to the use of sound apples and to protection of the premises from insect and rodent infestation.

3. SPRAY RESIDUE

The presence of poisonous spray residues resulting from sprays necessary in the production of apples presents a special problem in the manufacture of apple products, because such products must conform to specified limits with respect to their content of such materials.

Federal Tolerances. In the United States the Federal Security Agency has set a tolerance of 0.05 grain of lead per pound of apples and 0.025 grain of arsenic, as arsenic trioxide, per pound of apple.[483] A tolerance of 7 milligrams of fluorine per kilogram of apples was announced in 1944.[484] The situation concerning DDT (dichlorodiphenyltrichloroethane) residues is at present (early 1950) uncertain. Announcement of an official tolerance may be expected in the near future.

Residue Removal. Most apples used for processing have been washed at the fresh fruit packing plant to reduce the spray residue to within tolerances, but when orchard-run fruit is used it is necessary that a wash be used for the purpose of reducing these residues before processing. The problem of reducing the residue is not as complicated for the processor as for the fresh fruit shipper because the effect of the wash on the storage life of the fruit is not a consideration, and severe treatments may be used. Costs involved in special washing treatments, however, frequently make salvage economically impractical. The recent introduction of DDT for apple insect control promises to relieve the heretofore serious problem of arsenic, lead, and fluorine residues in certain apple products. Removal of DDT residues from apples is even more difficult,[485] however, but it is hoped that the amounts required for effective insect control will be sufficiently low that excessive residues will not accumulate.

When prepared from peeled fruit, the residue problem in dried, canned, and frozen apples and applesauce, is of no consequence,

[483] Announcement to Growers and Shippers of Apples and Pears, Federal Security Agency, Aug. 10, 1940.

[484] Federal Security Agency, *Federal Register,* Sept. 28, 1944, 9 F. R., 11836–37.

[485] G. D. Manalo, R. Hutson, E. J. Miller, and E. J. Benne, *Food Packer, 27* (13), 64 (1946).

since the residue remains in the peel. In the preparation of juice and juice products other than concentrates the problem is again negligible because most of the residue has been found to remain in the pomace.[486,487] The principal residue problems in apple products occur in the use of peel and core waste and in the use of pomace from pressing the juice. These materials contain a considerably higher residue content than the original fruit and may easily exceed the tolerance even when fruit below tolerance is used. Other products that offer residue difficulties are such concentrated products as dried apples prepared from unpeeled fruit and juice concentrates. In the preparation of products such as ciders, wines, and vinegar the lead present in the juice precipitates during the fermentation process but arsenic remains in solution. A process has been developed for removing arsenic from such products.[488] Metallic residues in fermented products can be eliminated by distillation processes.

4. CHEMICAL PRESERVATIVES

The Food, Drug, and Cosmetic Act authorizes the use of small quantities of harmless chemical preservatives where their use does not serve to conceal damage or inferiority or make the food appear better or of greater value than it is. Where used, however, the presence of the chemical preservative must be declared conspicuously as such in the labeling of the finished product. The law places the responsibility upon the manufacturer or shipper of a preservative or of a food containing it of assuring himself that a proposed preservative is in fact harmless from the standpoints of both acute and chronic toxicity before using it or advocating its use in foods.

Only sulfur dioxide, its acids and salts, and sodium benzoate have thus far been demonstrated as being harmless under the law when used in apple products. The former are used extensively in the manufacture of dried and frozen apple products. They are also employed to a certain extent in the manufacture of fermented apple products. Sodium benzoate is employed to a considerable extent in the manufacture of fresh apple juice, and less frequently in jelly,

[486] H. C. McLean and A. L. Weber, *New Jersey Agr. Expt. Sta. J. Series (unnumbered)*, 1–8 (1933); *Chem. Abstracts*, *28*, 5165.
[487] H. H. Mottern, A. M. Neubert, and P. D. Isham, *Wash. Agr. Expt. Sta. 48th Annual Rept. Bull.*, 368, 94 (1938).
[488] V. E. Speas and N. M. Mnookin, U. S. Pat. No. 2,080,582, May 18, 1937.

preserves, and butter. The advances being made in food technology are accompanied by the introduction of many new chemicals for the purpose of improving the color, texture, or other qualities of foods. Several of these, which have been proposed for use in preparing apple products, will be discussed under the respective products.

5. FERMENTED PRODUCTS

Manufacturers of apple products involving fermentation of the carbohydrate material into alcohol are required to comply with regulations applied to such processes by the government under which they operate. In the United States the Bureau of Internal Revenue, Treasury Department, is charged with the regulation and taxation of alcoholic products. Fermented products must comply with standards of identity and definitions promulgated by this agency for the various alcoholic beverages manufactured from apples. In addition specifications regarding methods of manufacture and controls of the manufacturing process have been established for purposes of taxation.

CHAPTER XI

PREPARATION AND PRESERVATION OF APPLES

A. Development of Dried, Canned, and Frozen Apples

In the United States one of the important commercial uses of apples is in the preparation and preservation of this fruit for use in prepared foods. The methods of preservation used are drying, canning, and freezing, with small amounts preserved for short periods by means of sulfur dioxide. The prepared fruit is preserved as slices, cubes, chunks, or pulped in the form of sauce. These products retain, more or less, not only the characteristic flavor but also the texture and in some cases the shape of apples when used in the cooked form.

A number of factors have contributed to the development of these products. Compared to fresh fruit, shipment and storage of processed apples are simplified and the quality of the product reaching the consumer is more easily controlled. In the case of the dried fruit an eight to one reduction in weight and a comparable reduction in volume become important considerations, particularly when fruit is shipped to distant or difficultly accessible markets. Perhaps equally important is the convenience to the consumer of obtaining fruit ready for use, thereby eliminating the waste and cost of preparing the fruit for use. A considerable portion of the cost of preparation and processing can be absorbed for the consumer through the use of seasonally surplus or second-grade fruit. By the use of specialized and expensive equipment, which is economically justified through volume production, preparation costs are reduced to a minimum.

The Production and Marketing Administration, United States Department of Agriculture, has established definitions and standards for grades of the commercially important apple products to serve as a convenient basis of sale in wholesale transactions and as a basis for determining loan value in warehousing. General provisions of these standards are presented to indicate those factors that de-

termine quality in these products. It is not mandatory, however, that apple products be prepared under these standards.

1. DRIED APPLE PRODUCTS

Drying is perhaps the oldest method used commercially for preserving apples, having been employed in the United States for about a century. Although production varies considerably from year to year depending on the fresh apple crop and market conditions, an average of about seven million bushels has been processed annually by drying in the United States since 1920.[489] Important but smaller quantities are dried in Canada; and Australia and the Union of South Africa are producing increasing amounts. Most of the dried apples produced are exported to European countries. In the United States the main outlets are to bakeries and institutions for use in pies, and most of the production is packed in containers holding twenty-five or more pounds.

Dried (Evaporated) Apples. Federal standards define dried apples[490] as "...apples that have been peeled, cored, and cut into segments and from which the greater portion of moisture has been removed. The fruit is sulfured sufficiently to retain a characteristic color. The finished product contains not more than 24% moisture by weight." The fruit may be prepared in the form of *rings* obtained by slicing cored apples at right angles to the core or *quartered* by cutting apples longitudinally into three, four, six, or eight approximately equal units. When apples are cut into more than eight approximately equal units the product is referred to as *sliced*.

Dried apples are graded on the basis of color and the absence of defects and foreign material. The presence of pieces damaged by bruises or showing the presence of cores, pieces of skin, calyxes, stems, dirt, bitter pit, corky tissue, or other defects detracts from the quality of the product and specified tolerances must be met for the various defects if the product is to be graded as U. S. Grade A or U. S. Fancy. Deviations from a bright, characteristic color and the presence of broken pieces also detract from the quality of dried apples.

Dehydrated Apples. In recent years a distinction has been

[489] *Agricultural Statistics*, U. S. D. A., 1942, 222; 1945, 148.
[490] *United States Standards for Grades of Dried Apples*, U. S. D. A., Prod. Marketing Admin., Nov. 1, 1943.

developed by the trade in which apples are termed *dried* or *evaporated* when the moisture does not exceed 24% by weight and *dehydrated* when the moisture does not exceed 3%. In order to prepare dehydrated apples it is necessary that the fruit be dried under vacuum and packed in hermetically sealed containers (page 252). Some effort has been made to distribute dehydrated apples in retail outlets, and during the war the Quartermaster Corps of the United States Army Service Forces purchased considerable quantities for use of the Armed Forces. Specifications[491] required, among other things that the product contain not more than 3% moisture by weight and the product be prepared from evaporated (dried) apples meeting U. S. Grade B, Choice, requirements. No undue delays should occur between the drying and dehydration steps. The product was purchased in two types, consisting of small and large pieces, was packed in hermetically sealed containers, and was used in the preparation of pies and sauce. The product rehydrates more readily than dried apples, requiring only 15 to 20 minutes in boiling water or 2.5 hours in cold water. Six parts of water are used to one part of dehydrated apple.

Apple Chops. Besides the conventional dried and dehydrated apples a substantial volume of apples is dried as chops. In preparing this product washed, whole apples are sliced and dried, frequently without treatment to prevent darkening. Small fruit, unsuitable for use in preparing products requiring peeling of the apple, may be used in preparing chops. Processing costs are considerably lower than for dried apples because the fruit can be handled in bulk and does not require peeling, coring, or trimming. The product is used in preparing apple butter, vinegar, and other products where color and blemishes such as bruises are not a factor in quality. Apple chops are more economically transported and stored than the fresh fruit and serve to extend the processing season of the products into which they are converted.

Dried Applesauce. Dried applesauce may be defined as the product made from sound ripe apples, after suitable preparation, pulping, and processing and from which the greater part of the moisture has been removed. Extensive commercial production of

[491] *Tentative Specification C.Q.D.*, Quartermaster Corps, No. 78C, Feb. 5, 1946.

dried sauce has not been realized although this product reconstitutes more rapidly than do dried apples.

Apple Flour (Powder). Apple flour may be defined as dehydrated apples that have been reduced to powder form by grinding.[492] The low moisture content necessary to permit grinding to powder form results in a highly hygroscopic product that must be held in hermetically sealed containers to prevent caking. Apple flour is produced only in limited quantities for therapeutic use, mainly in the treatment of infant diarrhea.

2. PRESERVATION BY CANNING

Although apples were canned commercially before 1920 this product did not reach an important place as a canned food until then. Since 1920 the production trend for canned apples and canned sauce has been upward, increasing from about four million bushels used for this purpose to an average of over nine million bushels during the five year period, 1940 to 1944.[493] Unlike most canned fruits, apples are usually canned without added sugar sirup and are not a dessert product. Practically the entire production is in large containers for use by bakeries and institutions in making pies. The dessert product prepared from apples is canned in the form of sauce to which sugar is usually added. Sauce is canned mainly in small retail containers and now makes up roughly half of the canned apple pack. Besides the United States only Canada produces appreciable quantities of canned apples and sauce. Most canned apples are marketed domestically although some are exported, chiefly to Britain.

Canned Apples. "Canned apples are prepared from sound, properly ripened fresh fruit of *Malus sylvestris* (*Pyrus malus*) by proper peeling, coring, trimming, and washing; may be packed with or without sirup; and are sufficiently processed by heat to assure preservation of the product in hermetically sealed containers."[494] The fruit is sliced by cutting the apples longitudinally. The product and packing medium must occupy not less than 90% of the total volume capacity of the container and may be certified as *heavy pack*

[492] F. Zago, *Ind. ital. conserve aliment., 9,* 19 (1934); *Chem. Abstracts, 28,* 2805. A. Piegai, *Ind. ital. conserve aliment., 10,* 67 (1935); *Chem. Abstracts, 29,* 6094.

[493] *Agricultural Statistics,* U. S. D. A., 1942, *222*; 1945, 148.

[494] *United States Standards for Grades of Canned Apples,* U. S. D. A., Prod. Marketing Admin., Nov. 1, 1943.

if certain requirements as to weight of nonliquid contents are met.

The quality of canned apples is determined by color, uniformity of size, defects, and character of the fruit. In order to meet U. S. Grade A or U. S. Fancy requirements, canned apples must possess a uniform, bright color typical of the variety and must meet specified tolerances with respect to uniformity of size, intactness of segments, and freedom from defects such as carpel tissue, sepals, skin, bruised areas, and insect or disease injury. In addition, the product must be of uniform, tender texture with a minimum, specified amount of mushy fruit.

Canned Applesauce. "Canned applesauce is the product made from sound, fresh apples (*Pyrus malus*) of proper ripeness, after proper washing, peeling, coring, pulping, and processing; with or without the addition of sugar (sucrose); packed in hermetically sealed containers, and sterilized by heat."[495] The containers must be filled to not less than 90% of their total volume capacity and be free from excess added liquid.

The quality of sauce is determined by color, consistency, finish, defects, and flavor. U. S. Grade A or U. S. Fancy canned applesauce possesses a uniform bright color typical of the variety and free from pink or brown tints. When emptied from the can it forms a slightly mounded mass without separation of free liquor and has a fine-grained finish free from lumps and not pasty. It must be reasonably free from defects such as particles of seeds, flecks from bruised portions, peel, and portions of carpel, and have a natural flavor and aroma approaching a fresh apple flavor.

Canned Dessert Apples. Canned dessert apples may be defined as peeled, cored, and sliced apples that are packed with medium sirup in such a way that the prepared pieces retain their shape, and are sufficiently processed by heat to assure preservation of the product in hermetically sealed containers. Canned dessert apples have remained more or less of a laboratory curiosity although commercial production has been attempted on a limited scale.

Canned Baked Apples. Canned baked apples may be defined as whole apples which have been prepared by coring but not peeling, cooked by baking, and sufficiently processed by heat to assure preservation of the product in hermetically sealed containers. The pro-

[495] *United States Standards for Grades of Canned Apple Sauce*, U. S. D. A., Agr. Marketing Service, Jan. 25, 1934.

cedure involved in preparing canned baked apples is somewhat expensive and the product has remained a specialty item.

3. PRESERVATION BY FREEZING

Just as the production of canned apples received its impetus as a result of the first World War, frozen apples were unimportant commercially until the recent war. The shortage of tin for containers was largely responsible for this development, as no tin was allocated for canning apples for civilian use during the war period. Both sliced apples in large containers for the bakery trade and retail containers of sauce became important frozen fruit products. In 1944 nearly 64 million pounds of apples and sauce were frozen and this fruit ranked second to cherries among individual fruits in the amount preserved by freezing.[496] Production has been curtailed in recent years.

Frozen Apples. Tentative United States standards for grades of frozen apples[497] define frozen apples as being "...prepared from sound, properly ripened fruit of *Malus sylvestris* (*Pyrus malus*) by peeling, coring, trimming, and washing; may be packed with or without sugar or sirup; and are frozen and stored at temperatures necessary for the preservation of the product." They may be prepared as slices by cutting the apples longitudinally or as rings by cutting the apples transversely to the axis.

The quality of the product is determined by flavor, odor, color, uniformity of size, defects, and texture. U. S. Grade A or U. S. Fancy frozen apples must possess normal flavor and odor, and be reasonably uniform in color typical of the variety. The segments must be of reasonably uniform size and meet specified tolerances with respect to the presence of defects such as carpel tissue, sepals, skin, bruised areas, and insect or disease injury. In addition the fruit must have a uniform, tender texture with a specified minimum of mushy fruit.

Frozen Applesauce. United States standards have not been established for frozen applesauce. This product may be defined, however, by analogy to canned applesauce with the exception that the product is preserved by freezing instead of by heat in hermeti-

[496] *Agricultural Statistics*, U. S. D. A., 1945, 193.

[497] *Tentative United States Standards for Grades of Frozen Apples*, U. S. D. A., Prod. Marketing Admin., Aug. 1, 1945.

cally sealed containers. Quality is determined more or less by considerations similar to those determining the quality of canned sauce.

4. PRESERVATION BY CHEMICALS

Sulfured Apples. The economies in labor realized through the use of modern equipment available for the quantity preparation of apples for culinary purposes have resulted in the development, in population centers, of small plants for the preparation of apples for use in cooked foods. Apples are peeled, sliced, and trimmed and delivered to nearby bakeries and institutions (page 311). In order to increase the keeping qualities and to prevent discoloration, the prepared fruit is treated with sulfur dioxide, and, where shipments involve some distance, the product is held under refrigeration. This development has reached considerable importance in population centers where the demand for prepared fruit warrants such service.

Brined Apples. Limited quantities of apples are preserved by barreling the prepared fruit in brine containing sufficient sulfurous acid to prevent spoilage. Preservation of apples by brine is not as common as for certain other fruits, such as cherries, and interest in the product appears to be limited to the British Commonwealth. Brined apples are remanufactured into products such as candied apples.

B. Apples Used for Drying, Canning, and Freezing Preservation

1. VARIETIES

Characteristics Desired. Apples possessing good cooking quality are most desirable for use in preparing dried, canned, and frozen products. The general preference is for varieties of relatively high acid content, good flavor, and firm texture that withstands cooking without becoming mushy. Although preferences exist for those varieties that yield a white or light colored product, this is not a necessary quality of a first-grade product. Regularity of shape and characteristic size of the fruit are also a consideration in mechanical peeling. A high sugar–water ratio is desirable, particularly in the preparation of dried products (see Chapter X, page 249), because of the increased yields obtained.

Commercially Important Varieties. The processing industry is secondary to the production of apples for the fresh market and depends

for raw material on the surplus and second grades of this fruit. Processors are therefore limited in their selection of those varieties available to them in commercial quantities. Unfortunately for processing, much of the fruit grown in the concentrated apple producing areas of the United States is of dessert varieties that are of inferior cooking quality. The varieties used depend somewhat on the apple crop and market conditions. In seasons of large crops only those varieties most adapted for processing may be used while in seasons of short crops and active markets even varieties of poor culinary quality may be processed.

Gravenstein, grown principally in California, is the only summer variety of importance for processing. Of the fall varieties, Jonathan, Grimes Golden, and Wealthy are considered suitable for processing. Winter varieties used extensively for processing, in approximate order of commercial availability, are: Winesap, Stayman Winesap, Rome Beauty, York Imperial, Yellow Newtown, Baldwin, Ben Davis, Rhode Island Greening, Northern Spy, Golden Delicious, Cortland, and Black Twig. Among other varieties suitable for processing are Wagener, Esopus Spitzenberg, Bellflower, Northwestern Greening, Ortley, Arkansas Black, Roxbury Russet, and Golden Russet.

It is not possible to draw exact distinctions among these varieties on the basis of their relative qualities when prepared by the different preservation methods because of variations within varieties as grown in the different producing areas. Maturity and condition of the fruit at the time of processing are also important considerations in determining the processing quality of the fruit.

Delicious, the most extensively grown variety in the United States, is considered unsuitable for processing because of its low acid content and its tendency, particularly when overmature, to break up during preparation and processing. Its irregular shape makes peeling difficult. McIntosh, another important variety of the dessert type, possesses an undesirably soft texture which breaks up during processing. Both of these varieties may be used for processing, however, during seasons of short fruit supply. Studies on treatments with solutions of calcium salts to increase the firmness of canned and frozen apples (page 300) suggest the possibility of improving the quality of several varieties that tend to become excessively soft or mushy when baked in pies. The blending of varieties is considered advantageous in the production of a uniform, high-quality sauce but is not recommended in

preparing canned, dried, or frozen apples because of differences found among varieties in color and firmness.

2. GRADES OF APPLES USED

Grades of apples used for processing vary from field-run fruit to culls of an arbitrarily established minimum size. In most instances apples purchased from packing houses will consist of definite grades sorted out in preparing the crop for the fresh market and are purchased on the basis of that grade. Field-run fruit consists of all grades as they are harvested. United States standards for grades of cannery apples were established in 1930[498] to facilitate purchasing of processing fruit.

U. S. No. 1 (Cannery). This grade consists of apples of one variety which are not overripe; which are free from decay, worm holes, freezing injury, internal breakdown, and from any defect which cannot be removed during the usual commercial preparation for use without causing a loss of over 5%, by weight, of the apple in excess of that which would occur if the apple were perfect.

U. S. No. 2 (Cannery). This grade consists of apples of one variety which are not overripe; which are free from freezing injury, internal breakdown, and from any defect which cannot be removed during the usual commercial preparation for use without causing a loss of over 25%, by weight, of the apple in excess of that which would occur if the apple were perfect.

Ciders. This grade consists of apples which do not meet the requirements of either of the foregoing grades. *Minimum size* may be fixed by agreement between buyer and seller. Apples below this specified minimum size are classified as ciders.

Effect of Grade on Yield and Quality. A number of factors enter into determining the value for processing of the various grades of apples. The yield of finished product is markedly affected by the size of the fruit and the amount of injury that must be removed by trimming. Apples should be at least 2.25 inches in diameter to peel well by machine. Table 32.A shows the relation between size of apples and percentage waste in peeling and coring. Labor costs in peeling small apples and the labor involved in trimming irregular and damaged fruit

[498] *U. S. Standards for Cannery Apples,* U. S. D. A., Food Distrib. Admin., July 23, 1930. Resissued Aug. 30, 1943.

are considerably greater per unit weight of finished product than with larger or perfect fruit.

The quality of products such as dried, canned, and frozen apples is determined to a considerable degree by the wholeness of the pieces and thus trimmed sections detract from the finished quality. In plants manufacturing sauce, trimmed and broken pieces can be diverted to the sauce preparation line. The increased labor in trimming makes the production of a high grade product more difficult because of the danger that all damaged tissues will not be observed on the inspection belt. When all factors are considered it is frequently found that a considerably higher initial cost for good quality fruit can be absorbed through increased yields, increased quality, and lower labor costs.

3. CONDITION OF FRUIT

The factors governing the quality of apples for fresh market use apply equally in determining the quality of this fruit for processing, and the same care must be exercised in picking and handling if the best quality processed products are to be obtained. Flavor, texture, and

TABLE 32A. Relation of Size to Number of Apples per Bushel and Waste in Preparation[a]

Size, inches	Apples per bushel	Waste, %
2.25–2.5	275	40
2.5 –2.75	200	30
2.75–3	160	20–25
3 –3.75	135	—

[a] W. D. Pheteplace, Jr., *Food Inds., 10,* 193 (1938).

general quality lost through improper handling of the fruit cannot be regained by processing and preservation. The fruit should be mature, firm, and free from disease or decay. The major portion of the apples processed is stored in the open or in common storage and used during the relatively cool early winter months while its condition remains good. Improved quality may be obtained from those varieties having a soft texture, such as Delicious and McIntosh, if they are processed as soon as they become mature and before the fruit begins to mellow. Although the processing season can be extended for several months by proper cold storage of the fruit this practice is not generally followed because of the added costs involved.

C. Fruit Preparation

1. WASHING

The major portion of apples used in processing are obtained from fresh fruit packing houses and have therefore been washed to remove spray residue and are free from decay. It is generally advantageous to wash and sort the fruit before preparation, however, particularly when field-run apples are used or when packing-house fruit has been stored for some time. Special continuous washers, employing water under pressures of 100 to 125 pounds per square inch, have been developed for cleaning apples. If the peelings and cores are to be used in the preparatioin of juice, or juice products, or if the pomace is to be used for feeding or for pectin manufacture, the apples may be washed in an acid or dilute lye solution at an elevated temperature, followed by thorough rinsing, in order to reduce the spray residue well below government tolerances.

2. PEELING AND CORING

Mechanical Peeling. Most apples prepared for preservation are peeled by machines that mechanically pare the fruit. The machines usually operate by rotating the apple about its core on a spindle while a hinged or "floating" peeling knife follows the contour of the rotating fruit, removing a narrow strip of peel. A circular coring knife may be used to remove the stem, calyx, and seed cells in the same operation. Machines available vary from simple, hand-powered units in which the operator impales the fruit on the spindle, to large, power-driven multiple units in which the operator merely places the fruit in receptacles. The capacity of the machines varies but for each machine it is usually determined on the basis of number of fruit peeled rather than on a tonnage basis because of the wide variations in size of fruit. The more automatic, multiple unit machines are rated at from 50 to 75 apples per minute. Grading of the fruit by size is desirable to speed up the work.

Chemical and Steam Peeling. The use of hot lye solutions has been suggested for peeling apples. In experimental lye peeling a saving of 60% in peeling loss was realized and use of wetting agents in conjunction with lye reduced the immersion time and temperature required.[499] After the lye treatment the fruit is thoroughly washed with

[499] J. G. Lankler and O. M. Morgan, *Food Inds., 16,* 888 (1944).

high-pressure water sprays to complete the removal of digested tissue. Recently, continuous, high-pressure steamers, developed for peeling vegetables, have been employed to peel apples. The principle of these units is to subject the fruit to a high temperature for a short period during which the skin and a thin layer of fruit is cooked soft. The fruit is then subjected to high-pressure water sprays that re-

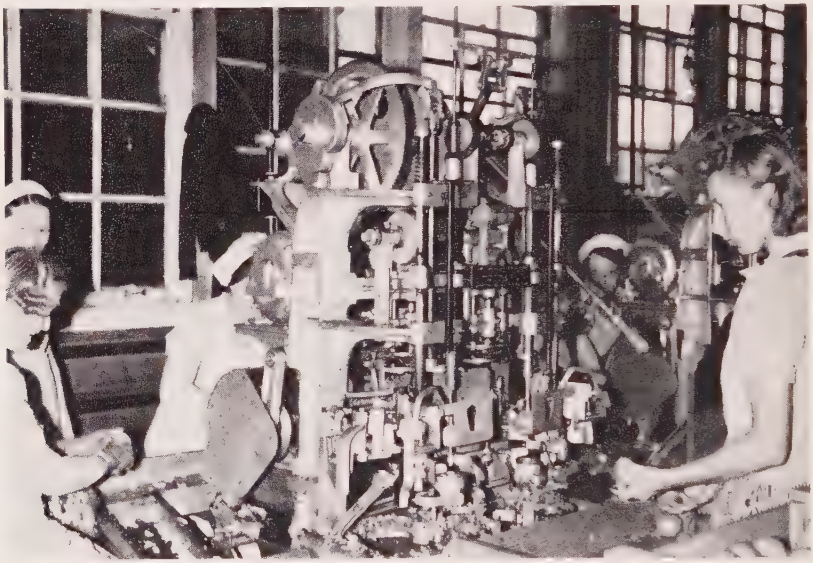


Fig. 64. Apple peeling and coring (courtesy Western Canner and Packer).

move the loosened skins and softened flesh. Automatic rotary type steam-tight valves are placed on each end of the steamer to permit continuous feed and discharge. Apples peeled by the lye or steam process are cored in a separate operation to remove stem, calyx, and seed cells.

3. TRIMMING AND SLICING

Bits of skin, bruises, and defects remaining after the peeling operation are removed from the fruit by hand as it moves along an inspection belt. The fruit is then sliced or cut to the desired form. A number of different types of cutters are manufactured for preparing the various cuts. Apples cut into segments or slices are usually forced

Fig. 65. Apple inspection and trimming line (courtesy Western Canner and Packer)

Fig. 66. Apples, sliced as rings, leaving inspection line (courtesy Western Canner and Packer).

through radial knives, the number depending on the size segments desired and the size of the fruit; while being held in position by a rod through the core opening. Rings may be cut by machines that pass the fruit over a series of knives while it is held with the core opening at right angles to the cutting edge. Kraut cutters are often used to slice unpeeled apples in the preparation of chops. After slicing the fruit is usually reinspected so that residual core material and defects missed in the first inspection can be removed. Broken or trimmed pieces may be separated for lower grade packs or for use in preparing sauce.

4. PREPARATION LINE

To permit efficient operation the equipment used in preparing apples is arranged in a *preparation line* so that the fruit passes automatically from one step to the next with a minimum of attention by the operators. The line arrangement varies somewhat with individual operators but is designed to permit the greatest possible efficiency with as little delay as possible after the fruit is peeled and cored so that darkening from oxidation is held to a minimum. The efficiency of the peeling, coring, slicing, and trimming operations is an important factor in determining the cost and quality of the finished product. In assembling equipment for an apple preparation line it is imperative that the cut fruit be kept from contact with iron and copper to prevent discoloration.

An apple preparation line may consist of a roller conveyor on which the apples are dumped and which removes leaves and other extraneous material. This conveyor feeds the fruit to a washer which in turn delivers the fruit to a conveying belt that carries it to the peeling machines. A single conveyor belt may supply a large number of peelers. Another conveyor belt, passing under the peelers, may be used to catch and remove the peel and core waste to a hopper for storage until it can be used or disposed of. It is the general practice to submerge the peeled fruit in a dilute salt solution for a short period, usually in a conveyor flume, to inhibit darkening (page 259). The peeled and cored apples may be flumed to inspection belts where they are trimmed by hand and delivered to the slicing machines. It is desirable to screen the sliced fruit in order to remove seeds and fines, whereupon it passes onto a final inspection or sorting belt. The prepared fruit then passes to the preservation line. From 25 to 45% of the fruit is lost in

the peeling, coring, and trimming operations, depending on the size and condition of the fruit (page 282).

Water washes appear unavoidable in preparing apples for processing and fruit that is to be canned or frozen is commonly dipped or soaked in an aqueous solution to remove oxygen (page 297), prevent discoloration (page 306), or as a firming treatment (page 300). Such treatments result in loss of sugars and other soluble flavor constituents by leaching and prolonged or unnecessary contact of the prepared fruit with water should be avoided. Laboratory studies have shown that losses by leaching may range from a minimum of about 5% of total sugars present for an immersion time as short as 1 minute, to a maximum of about 50% for a 24 hour soaking period.[500a] Smaller losses would be expected as the concentration of leached solids in the bath increased with use.

D. Preservation by Drying

1. ENZYME INACTIVATION

The enzyme systems present in apples (Chapter V, page 83) make it necessary that some treatment be given the prepared fruit to prevent it from becoming dark and developing off-flavors during drying and subsequent storage. Of the many agents useful in inhibiting oxidase activity none has been found equal to sulfur dioxide in preserving the desired color, flavor, and general quality of dried apples, and its use has become a generally accepted practice except in preparing apple chops. Steam blanching has been used to a limited extent to inactivate enzymes during the drying operation, but, if darkening is to be prevented during later storage, the product must be sulfured before packaging. Steamed fruit tends to soften and become mushy on rehydration. An interesting study on cellular changes in fruit during blanching and dehydration[500] showed that blanching before drying removed the air from the tissue and softened the cell walls, thereby permitting more rapid removal of moisture. The blanched fruit dried to a bright, translucent condition.

Sulfuring. The methods of applying sulfur vary considerably as does the amount of sulfur added.[501] To maintain the desired quali-

[500] A. S. Crafts, *Food Research, 9,* 442 (1944).

[500a] A. M. Mylne and C. G. Seegmiller, *Food Technol., 4,* 43 (1950).

[501] J. D. Long, E. M. Mrak, and C. D. Fisher, *Univ. Calif. Agric. Expt. Sta. Bull.,* 636, 1940.

ties of dried apples it has been found necessary to incorporate an excess of sulfur dioxide to allow for losses occurring during preparation, handling, and storage.[502] Whereas 800 parts per million, as sulfur dioxide, is considered sufficient for protection during domestic use, dried apples intended for export, shipment through tropical climate, or prolonged storage may be prepared with a sulfur dioxide content as high as 3000 parts per million. When the sulfur dioxide content declines to 500 parts per million the fruit requires resulfuring.[502] When dried apples once darken during storage, subsequent exposure to sulfur dioxide will not return the fruit to its original color.

A preliminary sulfur treatment is usually given apples after trimming to serve as a bleach and to protect them against darkening during preparation. This may be accomplished by passing the fruit through a tunnel containing sulfur dioxide gas or by immersing or spraying with a 1 to 3% solution of sodium bisulfite or sulfurous acid. The gas treatment is generally preferred because lower yields result from leaching of soluble solids in water solution (page 287). A preliminary dip in a cold 2% solution of sodium citrate for 3 minutes prior to sulfuring has been observed to improve retention of sulfur dioxide and a light color.[503]

The main sulfur treatment is applied to the fruit after slicing. The sliced fruit may be spread out on drying trays and placed in sulfuring chambers prior to drying or the sulfur may be applied during the actual drying operation as in the kiln-type dryers. The sulfur dioxide gas is produced by burning sulfur in shallow pans or in specially constructed burners. The concentration of sulfur dioxide obtained in this way varies but probably does not exceed 7%, by volume, of the atmosphere about the fruit. The addition of 3% sodium nitrate to powdered sulfur has been found to increase the rate of burning approximately fivefold and approximately to double the sulfur dioxide concentration.[504] The fruit may be exposed to the gas for as short a period as 20 minutes, when sliced fruit is treated for tunnel drying, or it may continue during the entire drying operation as in the case of kiln drying. It is necessary that sulfur penetration be complete to avoid internal darkening during drying.

[502] P. F. Nichols and H. M. Reed, *Fruit Products J., 22,* 206, 247 (1943).
[503] E. M. Mrak, C. D. Fisher, and B. Bornstein, *Fruit Products J., 21,* 297 (1942).
[504] E. C. Orton, *J. Council Sci. Ind. Research, 19,* 212 (1946); *Chem. Abstracts, 41,* 230.

2. DRYING

Apples are dried commercially only in mechanical or artificial driers, in contrast to fruits such as apricots, peaches, and grapes which are mainly sun dried. The technology of artificial drying has received considerable attention during the recent war years because of its importance in the preservation of a wide variety of foods, and many types of equipment have been developed for drying various products.[505] Water is relatively easily removed from apples to the level

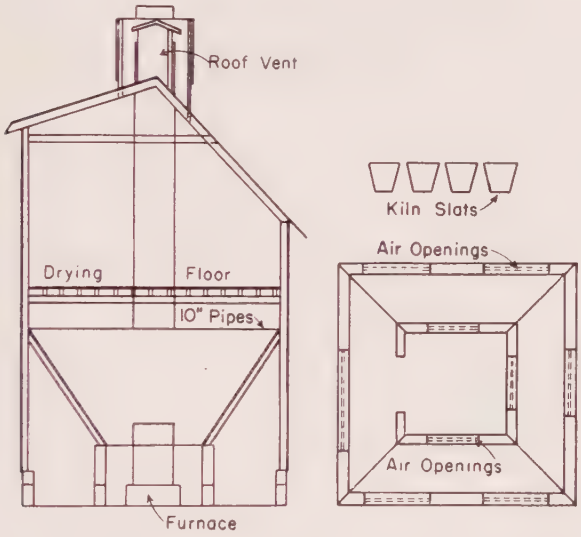


Fig. 67. Cross sections of simple kiln-type drier.[505] Some operators install fans in roof vent to speed drying by drawing air through fruit piled on floor (courtesy Avi Publishing Co.).

usually attained in the dried product (10 to 24% moisture, page 274) and the simpler types of driers are still used extensively. Kiln- or loft-type driers, probably the oldest type still in commercial use, and tunnel driers of the counter-current type are commonly used to produce dried apples. Secondary processing of the dried fruit to produce the dehydrated product (less than 3% moisture, page 274) requires the use of vacuum equipment.

[505] F. Rosseau, *Food Inds., 11,* 687 (1939).
[505a] E. M. Mrak, *Fruit Products J., 20,* 267 (1941)

Kiln (Loft) Driers. In their original form kiln driers consist simply of a slat floored drying room located over heating stoves. The hot air rising from the stoves and radiation pipes passes through the

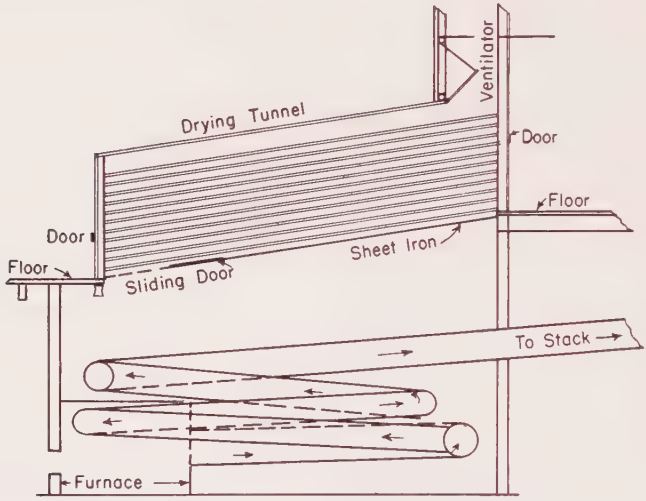


Fig. 68. Cross section of simple, inclined tunnel dryer.[505a] Apples are spread on trays, placed in upper end of tunnel, and moved progressively to lower end where they are removed when dry. Fans may be installed to recirculate air (courtesy Avi Publishing Co.).

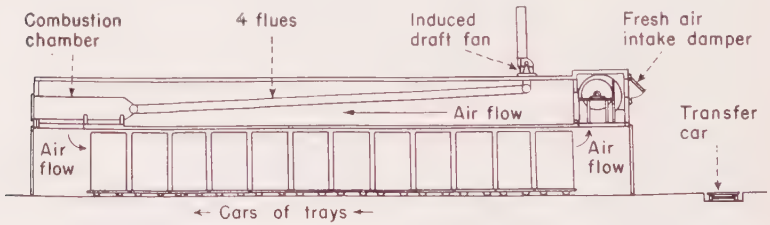


Fig. 69. Cross section of single-stage, counter-current, recirculating tunnel dryer.[505b]

fruit spread in a layer about 10 inches deep on the slatted floor and escapes through vents in the roof. This type of drier is inefficient in the

[505b] E. M. Mrak, *Food Inds., 14,* (8), 50 (1942).

use of heat, results in slow drying, and does not permit accurate control of the process. It is, however, more economical of labor and maintenance than tunnel-type driers.

A number of modifications have been developed to increase the efficiency of kilns and to speed up the drying process. Fans may be set in the wall of the furnace room or in the roof vents to force the heated air more rapidly through the fruit, thereby shortening the drying time. During the initial drying period, when drying is rapid, all of the hot gases are allowed to escape through the roof vents. As the drying progresses much of the air may be recirculated by fans, thus increasing the efficiency in heat consumption. The fruit on the kiln floor is turned several times during drying and drying times vary from 7 to 18 hours, depending on the temperature and the rate of air circulation. Air temperatures of about 150° to 165°F. are maintained and the rate of circulation varies considerably depending on whether or not natural draft is augmented by the use of fans. About 7 pounds of sulfur is burned in the furnace room during the initial hours of drying for each 3600 pounds of fresh fruit dried.

Tunnel Driers. Many modifications of tunnel driers have been developed for the drying of various foods. In counter-current driers the sliced, sulfured fruit is moved progressively through the tunnel in the opposite direction from the flow of heated air. The fruit is spread on trays at a rate of about two pounds per square foot to expose as much surface as possible to the air. The trays may be stacked on carts which are rolled through the tunnel or the trays may slide on runners. In one of the simpler tunnel arrangements the drying chamber is sloped so that natural draft may be used to move the heated air over the fruit. Fans may be installed to recirculate the air, thus permitting some control of the humidity.

In the more efficiently designed horizontal tunnels the recirculated air enters the tunnel at about 165°F. with a relative humidity of about 25% and is exhausted at about 130°F. with a relative humidity of about 65%. Air velocities range from 600 to 1000 feet per minute and over-all thermal efficiencies of about 40 to 50% may be realized. Some advantage is realized by drying apples in a two-stage operation. Because freshly prepared apples give up water relatively easily, it is possible to use an air temperature 10 to 20 degrees higher during the initial drying without danger of scorching the product. After the first stage the partially dried slices are finished in a second tunnel operated

at a somewhat lower temperature. A maximum temperature at the end of drying of 165°F. has been recommended for apples[506] with a relative humidity at this stage of from 5 to 10%. Table 33 presents comparative data on the operating characteristics of a counter-current type tunnel when used for apples and prunes. The rapid moisture loss from sliced apples permits the use of a considerably smaller drying area than is required for prunes.

Belt and Drum Driers. Although the commercial development of dried applesauce has not met with marked success, the product has the advantage of reconstituting more rapidly than dried apples. The

TABLE 33. Operating Characteristics of Counter-Current Type Tunnel Drier on Prunes and Apples[a]

Operating characteristics	Prunes	Apples
Capacity per 24 hours, gross fresh tons	10	10
Capacity per 24 hours, prepared fresh tons	10	7.5
Capacity per 24 hours, dry tons	4	1.5
Shrinkage in drier	2.5 to 1	5 to 1
Load per square foot, pounds	3.5	3
Drying time, hours	24	12
Spreading area in drier, square feet	5,714	2,500
Water evaporated per hour, pounds	500	500
Over-all thermal efficiency of plant, %	45	40
Air volume required, cubic feet per minute	22,532	29,600
Air velocity, feet per minute	750	730
Maximum temperature, hot end	165	160
Maximum humidity, hot end, %	25	20
Maximum humidity, cool end, %	65	65

[a] P. F. Nichols and A. W. Christie, *Calif. Agr. Expt. Sta. Bull.*, 485, 1930.

product is prepared by spreading prepared sauce (page 302) on heated drums[507] or stainless-steel belts.[508,509] After drying it is removed by scraper blades in the form of flakes or sheets. Sulfur dioxide may be used in preparing the sauce in order to obtain a light-colored product.

Vacuum Driers. To obtain the low moisture content required in dehydrated apples (less than 3%, page 274) at a practical rate and without damage to the product by heat, it is necessary that the final

[506] W. V. Cruess and A. W. Christie, *Calif. Agr. Expt. Sta. Bull.*, 330, 1921.
[507] W. W. Cowgill, U. S. Pat. No. 2,140,788, Dec. 20, 1938.
[508] H. W. Gerritz and J. L. St. John, *Food Inds.*, *11*, 369, 416 (1939).
[509] C. R. Stuntz, U. S. Pat. No. 2,155,453, April 25, 1939.

drying be conducted under vacuum. Low-temperature, vacuum drying of apples was investigated a number of years ago,[510] but it is only recently that commercial development of this type of dried apple has occurred. Dried apples are chopped or ground and spread on metal trays that can be heated with hot water or steam. After loading,

Fig. 70. Loading ground, dried apples on trays for vacuum dehydration (courtesy Western Canner and Packer).

the trays are placed in a steel shell capable of withstanding external pressure and the fruit is dried under vacuum by applying heat through the trays.[511] The vacuum process is highly efficient in the use of heat but thus far has remained a batch operation of rather limited capacity. The somewhat elaborate equipment required makes the process expensive. By compressing the ground fruit into ribbons before final drying the capacity of the vacuum chambers is increased

[510] K. G. Falk, E. M. Frankel, and R. H. McKee, *Ind. Eng. Chem., 11,* 1036 (1919). J. H. Buchanan and P. A. Zook, *Chem. & Met. Eng., 29,* 1097 (1923); *Chem. Abstracts, 18,* 869.

[511] C. R. Havighorst, *Food Inds., 16,* 258 (1944).

and packaging costs are reduced. Operation cost may also be reduced by lowering the moisture content of the dried raw material to about 12% in a preliminary drying step.[512]

3. FINISHING, PACKAGING, AND STORAGE

Finishing. Apples are removed from the driers when they reach an elastic, pliable condition and are placed in *sweating* bins for one or more days to permit equalization of the moisture. Water may be sprinkled on fruit that is too dry, or wet lots may be mixed with drier fruit to obtain the desired moisture content. After equalizing, the fruit is cleaned by screening and fanning to remove seeds, fines, and other foreign material. The fruit may be resulfured if necessary by spreading on trays and exposing to sulfur dioxide gas for several hours. Water may be sprinkled on the fruit prior to sulfuring, care being taken that the final moisture does not exceed 24% (page 274). The total sulfurous acid content of the dried fruit may be determined by distillation into neutral hydrogen peroxide and titration with standard base in the presence of bromphenol blue or by weighing as barium sulfate.[513] Moisture is determined by drying a ground sample for 6 hours at 158°F. in a vacuum not to exceed 100 mm. of mercury. Rapid methods for estimating moisture, such as distillation or the use of the Dried Fruit Association electrical moisture testers are more practical for plant control.

Packaging. The method of packaging is important in determining the storage life of dried apple products and it is advisable to package the fruit as soon as processing has been completed. Danger from mechanical injury, insect infestation, and loss of sulfur dioxide during bulk storage in bins increase the problem of maintaining quality. The sulfur in the fruit serves to repel insects but fumigation or other measures for controlling insects may become necessary.[514] Resulfuring during bulk storage may also be required to maintain sulfur content above the critical value required for color protection.

Dried apples are packed tightly in wooden boxes lined with waxed paper, by means of presses whereby most of the air between the individual pieces is expelled. Fruit dried to 24% moisture may be expected to retain its moisture content during considerable periods

[512] Anon., *Western Canner and Packer, 38* (5), 46 (1946).
[513] *Official and Tentative Methods of Analysis.* 6th ed., Assoc. Official Agr. Chemists, Washington, D. C., 1945.
[514] H. M. Reed, *Food Inds., 3,* 117 (1931). C. D. Fisher, *ibid., 17,* 1176 (1945).

of storage under ordinary conditions because it is in approximate equilibrium with atmosphere at a relative humidity of about 75% (page 252). An experimental study has been made on the use of pasteurization in dried fruit to eliminate mold, bacteria, and insect infestation,[515] and the use of electronic heat has been suggested for this purpose.[516]

The hygroscopic nature of dried apple tissue makes it imperative that special precautions be taken against moisture absorption when the moisture had been reduced to low levels as in dehydrated apples and apple flour. These products are packaged as soon as possible after removal from the vacuum chamber, preferably in an air-conditioned room, and hermetically sealed containers are required to prevent absorption of moisture with subsequent caking and loss of quality during extended storage.[517] A method of predicting the storage life of dehydrated apples, when packaged in moisture and vapor-resistant wrappings has been studied.[518] Insect-proof containers are recommended for packaging dried apples to be shipped to the tropics.

Storage. Dried apples, as all processed foods, deteriorate with age. In addition to spoilage by organisms such as yeast and mold, which occurs when the moisture exceeds 24%,[519] chemical changes that are not well understood take place in apples of lower moisture content and result in loss of flavor, color, and odor. Storage temperature and moisture and sulfur dioxide content of the fruit appear to be the principal factors affecting storage quality. A study of pectinic acids as related to the texture and quality of dried apples has shown that grade (as calculated from viscosity) of pectins present in the dried product may be used as an index of quality.[520] A straight-line relationship was found between the grade of pectin extracted and the quality of the dried fruit.

Moisture content has been found to be a prime consideration in the keeping quality of dried apples.[521] The orginal flavor, color, and odor was retained in dehydrated apples for periods of storage as long as three years at 77 F. when the moisture content was held

[515] C. R. Fellers, *Fruit Products J., 9,* 214 (1930).
[516] Anon., *Western Canner and Packer, 38* (8), 56 (1946).
[517] Anon., *Food Inds., 16,* 171 (1944).
[518] C. R. Oswin, *J. Soc. Chem. Ind., 64,* 67 (1945).
[519] C. W. Culpepper and J. S. Caldwell, *J. Agr. Research, 35,* 889 (1927). E. M. Bailey, *Conn. Agr. Expt. Sta. Bull.,* 341, 1932, p. 704.
[520] G. L. Baker and W. G. Murray, *Food Research, 12,* 129 (1947).
[521] C. W. Culpepper and J. S. Caldwell, *J. Agr. Research, 35,* 889 (1927).

below 3%. When moisture exceeded 10% deterioration of color became apparent within 120 days, and abnormal flavors and odors became apparent on storage for a year or longer. The rate of deterioration increased with increasing moisture content. The advantages in preparing dehydrated apples therefore are considerable when a high-quality product is required after storage under adverse conditions for prolonged periods. These advantages are lost, however, when dehydrated apples are prepared from dried fruit that has been allowed to deteriorate under adverse storage conditions.

Apples dried to from 20 to 24% moisture have been observed to deteriorate in color after 12 months storage at 50°F., whereas they retained their original color at 0°F.,[522] and elevated storage temperatures increase the rate of color deterioration.[523] More recent studies have shown that 32°F. storage is superior to 40°F. or higher temperatures in preventing browning, in retaining sulfur dioxide, ascorbic acid, and carotene, and in giving insect control of dried fruits.[523a] Dried apples were not harmed by storage at 80% relative humidity at 32°F. Even under optimum conditions of moisture content and packaging, dehydrated apples were observed to deteriorate in color and become unpalatable after two months storage at 130°F.[524]

Color retention is also closely associated with sulfur dioxide content and a critical amount of 500 parts per million was observed for dried apples.[525] Under conditions of high storage temperature, 98°F., the quality of dehydrated apples was found to be maintained at a higher level when packed in nitrogen or carbon dioxide gas than when packed in air.[526]

E. Preservation by Canning

1. SLICED APPLES

Removal of Oxygen. Fresh apple tissue contains relatively large amounts of gas, of which a considerable part may be oxygen (Chapter X, page 264). Oxygen destroys vitamin C and causes dark-

[522] W. R. Barger, *Ice and Refrig., 100,* 235 (1941).
[523] P. F. Nichols and H. M. Reed, *Fruit Products J., 22,* 206, 247 (1943).
[523a] W. R. Barger, W. T. Pentzer, and C. K. Fisher, *Food Inds., 20*(3) F1 (1948).
[524] Anon., *Food Inds., 16,* 171 (1944). D. G. Heberlein and L. E. Clifcorn, *Ind. Eng. Chem., 36,* 912 (1944).
[525] P. F. Nichols and H. M. Reed, *Fruit Products J., 22,* 206, 247 (1943).
[526] Anon, *Food Inds., 16,* 171 (1944).

ening of the fruit during processing and storage. In the presence of malic acid found in apples it causes serious corrosion of tin plate and eventually results in hydrogen springers and can perforations. It is therefore necessary that oxygen be removed from the fruit before it is sealed in the can. Several procedures have been developed for removal of oxygen from apple tissue. Thorough heating of the fruit with steam, hot water, or in a sugar sirup[527] have been used but have not become generally accepted procedures because of serious losses in flavor and nutrients by leaching (page 287).

The use of a vacuum of 24 inches or higher has been found more effective in removing gas than a short-time steam exhaust.[528] Table

TABLE 34. PER CENT GAS[a] IN DIFFERENT VARIETIES OF APPLES BEFORE AND AFTER EXHAUSTING IN DIFFERENT WAYS[528]

Variety	Untreated tissues	3 minute steam exhaust	Vacuum exhaust	Both vacuum and steam exhaust	After soaking in 1% brine overnight at room temp.
Winesap	16.3	9.4	3.7	0.6	13.8
Stayman	19.1	7.6	4.0	1.6	7.6
N. W. Greening	18.5	9.6	2.5	0.0	14.3
Paragon	19.0	9.4	3.8	1.3	13.5
Delicious	21.2	9.3	7.2	0.0	17.9
Grimes Golden	23.5	11.9	4.9	2.1	18.3
Baldwin	22.6	11.5	6.9	0.0	18.6
Ben Davis	28.8	10.7	8.2	1.3	24.1

[a] Per cent gas calculated from specific gravity of fruit and specific gravity of expressed juice.

34 shows the relative effectiveness of several treatments in removing gases for a number of apple varieties.

A number of patents have been granted covering processes for vacuum treating apples. The fruit may be submerged in a liquid or sirup while being subjected to a vacuum.[529] When the vacuum is released the liquid flows into the spaces previously occupied by the gas. Another procedure consists of subjecting the prepared fruit in bulk to a mechanically produced vacuum of 28 to 29 inches and then releasing the vacuum with steam, so that the gas spaces are filled with

[527] S. L. Crawford, U. S. Pat. No. 1,631,017, May 31, 1927.
[528] C. W. Culpepper and H. H. Moon, *Canner, 68* (8), 21 (1929).
[529] W. S. Sellars, U. S. Pat. No. 1,279,379, Sept. 17, 1918.

water vapor.[530] Still another process consists in conducting the evacuation and steaming within the can in which the apples are to be preserved.[531]

Soaking is another commonly used process for removing oxygen. This process depends on anaerobic respiration of the fruit, while sub-

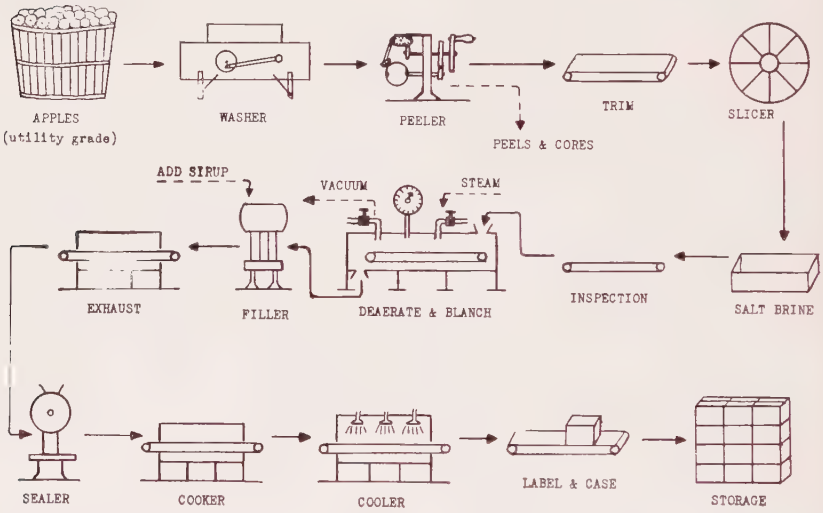


Fig. 71. Flow diagram of production of canned apple slices by "vacuum and steam" process. Soaking tanks (or continuous soaker) and continuous steam blancher replace "deaerate and blanch" step when soaking process is used (courtesy Dr. C. H. Hills[529a]).

merged in a dilute brine, to replace the oxygen with carbon dioxide. The length of time necessary to soak the fruit depends on the temperature of the soaking solution. Soaking for 20 to 30 minutes has been found to remove oxygen completely from apple tissues when the temperature was maintained at 120° to 130°F.,[532] whereas at least eight hours were necessary when the fruit was held at room temperature. Low-temperature soaking is advantageous with softer varieties

[529a] C. H. Hills, *Vermont State Hort. Soc. Proc., 1948*, 102.
[530] E. G. Grab, U. S. Pat. No. 1,557,358, Oct. 13, 1925.
[531] O. H. Hansen, U. S. Pat. No. 1,625,207, April 19, 1927.
[532] B. S. Clark, *Canning Age*, Feb. 1923. Reference and data from A. W. Bitting, *Appertizing; or, The Art of Canning*. The Trade Pressroom, San Francisco, 1937, p. 131.

that do not withstand steaming well because the prolonged soak tends to firm the flesh. High-temperature soaking is usually preferred because it may be made continuous, thereby avoiding the need for extensive soaking tank capacity. Soaking at 120°F. tends to give a better, lighter colored product than do higher temperatures. Solutions containing 3% of salt are usually employed for short period soaking while 1% of salt is used in the longer treatments to avoid absorption of excessive amounts of salt by the fruit. Gases remaining in the apple tissue after soaking make canned apples prepared by this method whiter in color than is the case where vacuum treatment or steaming is used to remove the gas. After soaking the apples are thoroughly washed to eliminate as much of the salt as possible before processing, since salt in the presence of malic acid intensifies can corrosion.

Blanching. Because sliced apples are canned principally for use in bakery products, in which only the solid fruit is used, the trend has been to pack this fruit as solidly as possible and use water only to fill small air spaces between the slices. To obtain a maximum fill of fruit it is necessary that the apples be steamed or blanched to soften the slices so they may be tightly packed without breaking. The fruit may be steamed on a continuous belt from 2 to 6 minutes at 180° to 210°F. or immersed in water varying in temperature from 190° to 210°F. for 2 to 6 minutes. Longer blanching times result in increased uptake of water by the tissue and thus in higher drained weights but care must be taken to avoid excessive softening or the fruit will become mushy. Steam blanching tends to yield a higher drained weight than water blanching. After blanching the fruit is usually sprayed with cold water to firm it and make filling easier.

Filling. Cans may be filled by hand or with automatic fillers and it is desirable to check ingoing weights to assure even fills. It is usually necessary to press or force the fruit into the cans to obtain the desired drained weight. Boiling water is used to fill spaces left between the slices and this may be conveniently added before the apples are filled in to assure the complete removal of entrapped air.

Processing. If the steamed fruit is filled into cans without cooling, further exhaust may not be necessary to obtain satisfactory vacuum in the can. With cooled fruit it is sometimes necessary to exhaust No. 10 cans for as long at 15 minutes in water held at 190°

to 200°F. to obtain a sealing temperature of 180°F. Because heat conduction is slow in solid-packed fruit it is necessary to use somewhat longer cooks than with water-packed fruit. The actual time of cook depends on the sealing temperature and the fill of the container. As long as 28 minutes may be required to obtain a temperature of 185° in the center of the can of solid-packed fruit, whereas loosely filled cans may be sterilized in a much shorter time. An extended water cool is necessary to avoid darkening or development of a pink color caused by continued cooking in the stack. Only plain Type L plate cans are recommended for canning apples because of the corrosive action of malic acid. In order to be certified as "Heavy Pack" canned apples should have a drained weight of at least 96 ounces for No. 10 cans.

Firming Treatments. The use of calcium salts and pectic enzymes in preparing apple slices for canning and freezing preservation and fresh use has recently been investigated with the object of firming the flesh of those varieties which normally are too soft for commercial processing or for apples which have matured beyond the point usually considered desirable.[533–535] The process depends on the reaction of calcium ions with pectinic acids and their potassium and sodium salts to form insoluble pectates within the fruit tissue. Various calcium salts (chloride, phosphate, citrate, malate, and lactate) seem to give comparable firming when used on an equal calcium content basis, with some indication of a slight superiority of the lactate both in firming effect and calcium uptake.[535a] Apples treated with the phosphate, malate, or lactate were free from the occasional slight salty flavor observed with the chloride. The calcium may be added by dipping, impregnating, or cooking the prepared fruit in a dilute solution of a calcium salt. Increasing the acidity of the dipping solution to the range of *p*H 2.7 to 2.9 with citric or hydrochloric acid has been found to accentuate the effectiveness of the calcium treatment as well as accelerate penetration of sulfur dioxide when used to prevent dark-

[533] Z. I Kertesz, *Canner, 88,* (7), 26 (1939). J. J. Powers and W. B. Esselen, Jr., *Fruit Products J., 25,* 200, 217 (1946).
[534] G. L. Baker, *ibid., 26,* 197 (1947). Anon., *Canning Trade, 69* (41), 9 (1947).
[535] Z. I. Kertesz, *Food Packer, 28* (6), 30 (May, 1947). W. B. Esselen, Jr., W. J. Hart, Jr., and C. R. Fellers, *Fruit Products J., 27,* 8 (1947).
[535a] K. Holgate and Z. I. Kertesz, *Fruit Products J., 28,* 37, 42 (1948).
[535b] K. T. Williams and A. Bevenue, *Fruit Products J., 29,* 136 (1950).

ening. The amount of calcium added depends on the variety and condition of the fruit being processed and is controlled by the length of treatment and the concentration of the solution used. It is necessary to add calcium to the bath periodically during use to replenish that removed by the fruit. A rapid, modified soap method has been developed for use in determining the calcium content of dip baths.[535b] To obtain uniform firming it appears desirable to remove the gas from the slices before dipping. Treatment with a combination of calcium chloride and

Fig. 72. Effect of calcium firming treatments on appearance of pies prepared from McIntosh apples: (*a*) no treatment; (*b*) slices deaerated and filled with 0.5% calcium chloride solution (courtesy Avi Publishing Co.).[536]

sodium acetate was found useful in firming overripe apples which did not respond to calcium alone and the addition of pectase to this treatment resulted in additional firming.[536] These developments promise to increase considerably the number of varieties suitable for canning and freezing preservation. Federal regulations with respect to added chemicals must be complied with in adding calcium salts to canned and frozen apples.

Vitamin Fortifications. The addition of ascorbic acid to canned apples and sauce, immediately before filling, enhances their nutritive

[536] C. H. Hills, C. S. Nevin, and M. E. Heller, *Fruit Products J., 26,* 356, 379 (1947).

value and has a beneficial effect in retaining a light color, particularly when these products are packed in glass and the reducing action of the fruit acids on tin is not present. Vitamin C has been found to remain stable when added to canned apples.[537] Vitamin C fortification of commercially canned apples and sauce is not generally practiced, however, because of the added expense. In the case of apple slices the value of such fortification might be largely lost during the final use of the fruit in preparing pies.

2. APPLE SAUCE

Applesauce is usually made from peeled, cored, and trimmed fruit. Yellow-skinned varieties may be processed without preliminary preparation other than washing and trimming, but the resulting sauce is inferior in flavor, color, texture, and appearance,[538,539] and does not meet standards for grades of canned sauce (page 277). The anthocyanin pigment present in red-skinned varieties makes peeling essential to avoid a red sauce that discolors in tin containers. The quality of the sauce can usually be improved and is more easily standardized throughout the season if two or more varieties are blended. Blending is best accomplished by mixing the whole fruit or the peeled, cored, and trimmed fruit before processing. Factors such as the acidity, flavor, and texture of available varieties determine the proportions of each variety used.

The preparation of sauce consists of slicing, precooking, and pulping the prepared fruit. In order to produce a light, bright-colored sauce these three steps should succeed each other without delay so that darkening from oxidation is held to a minimum. If peeled and trimmed apples are not used as soon as they are prepared they are held under a dilute salt solution, after which they are washed to remove excess salt before cooking. Slicing or chopping the apples promotes rapid heat penetration and permits a short precook. Short cooks are desirable to prevent a pasty texture, particularly when sauce is prepared from the soft-fleshed varieties. The fruit may be sliced by means of slicers used in preparing apples for drying or by chopping in rapidly revolving knives set close together.

[537] S. S. Zilva, T. N. Morris, and E. O. V. Perry, *Dept. Sci. Ind. Research Brit., Rept. Food Invest. Board, 1934,* 203 (1935).
[538] C. R. Fellers, *Fruit Products J., 8,* 9, 20 (1928); *Glass Container, 8* (2), 11 (1928). G. L. Marsh, *Fruit Products J., 11,* 297, 315 (1932).
[539] A. M. Neubert and H. H. Mottern, *ibid., 20,* 68, 89, 92 (1940).

Precooking. Precooking is most satisfactorily accomplished by applying clean steam directly to the sliced fruit. In this way there is a minimum delay in heat transfer and the fruit may be kept under a blanket of steam to retard oxidation. Continuous precookers have been developed which move the chopped fruit through a heating tube by means of screw conveyors or propellers while live steam is injected into the mass. Pressure cookers are also used in cooking apples for sauce.[540] The prepared apples are filled, either whole or chopped, into

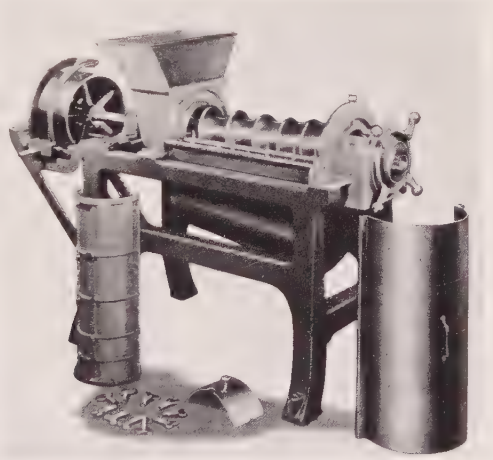


Fig. 73. Screw-type finisher used in the pulping of applesauce.[540a]

the cooker and steam is then injected into the fruit mass under pressure. Mechanical agitation is required to insure thorough mixing and heat penetration.

Precooking may also be accomplished in tanks supplied with perforated steam coils or in steam-jacketed kettles. Mechanical agitation is necessary in both methods, and when steam-jacketed kettles are used it is necessary to add a small amount of water before cooking to avoid scorching. The precook is completed when the fruit has been thoroughly heated and softened. A better texture can be obtained from soft-fleshed varieties if the precook is limited to a thorough heating of the fruit, in which case the final disintegration is accomplished by mechan-

[540] W. D. Pheteplace, Jr., *Food Inds., 10,* 193, 224 (1938).

[540a] A. E. Abrahamson, in M. B. Jacobs, ed., *Food and Food Products,* Vol. II. Interscience, New York, 1944, p. 178.

ical pulping. A short precook is also desirable to retain the natural, fresh flavor of the fruit. Sugar may be added before, during or after the precooking and pulping operations.

Pulping. The cooked apples are passed directly through a paddle or screw-type finisher. The texture of the sauce is determined to some extent by the size of openings in the screen; those having perforations from 0.052 to 0.062 inch in diameter yield a coarser grained product than do finer screens. The manufacture of unfinished or home-style sauce has been suggested by several workers but large-scale commercial production has not been realized. Special care in removing defects and seed cells is required in this type of product since these materials are not removed by screening.

From the pulper the sauce may be passed directly to fillers but control of the finished quality is more easily maintained by first transferring to a steam-jacketed balancing tank. If a balancing tank is used, mechanical agitation is necessary to maintain a uniform temperature. The consistency of the finished sauce is determined by the variety and condition of the apples used and by the amount of water added during the precook in the form of steam. Control is somewhat difficult because the hot sauce becomes considerably less fluid after cooling and cannot be accurately judged by observing the hot sauce before filling. Care is taken to avoid diluting the sauce unnecessarily during preparation so the finished sauce will not be watery. Consistency of the cooled product may be measured objectively by means of a consistometer.[541]

Filling. The heavy consistency of applesauce makes heat penetration slow and it is therefore desirable to fill the sauce into the containers while still hot. When a continuous chopping, precooking, and pulping line is used the finished sauce will be sufficiently hot, at least 180°F., to permit direct filling into cans by means of mechanical fillers commonly used in filling corn and other pulpy foods. The containers are filled as full as possible to reduce the amount of entrapped air, and sealed at once to insure a high vacuum. Although sanitary enamel cans hold applesauce with its original color over periods of storage, plain tin is used extensively because the action of the fruit acids on the tin exerts a desirable bleaching action not experienced in enameled cans.

Processing. Processing applesauce that has been filled at a temperature above 180°F. is not necessary but a short cook in water is frequently given as a safeguard against spoilage. After filling and cooking the cans are rapidly cooled in water to preserve the fresh flavor

[541] M. C. Adams and E. L. Birdsall, *Food Inds., 18,* 844 (1946).

and prevent pink discoloration caused by continued cooking in the stack. Because the product is subject to hydrogen springers, cool storage temperatures are recommended to increase storage life. Studies on the freezing of canned foods have shown that freezing has no effect on the quality of canned applesauce.[542]

3. DESSERT APPLES

Although practically all apples are canned without added sugar small packs of the dessert type have been produced. Experiments with this type of pack[543] have shown that an improved color may be obtained by subjecting the prepared slices to a vacuum of 24 inches of mercury or more for 10 to 15 minutes while submerged in a 10% solution of sucrose. The deaerated fruit was packed with a 35% sucrose sirup and No. 2 cans were processed from 10–15 min. at 212°F.

4. BAKED APPLES

Baked apples are prepared from whole apples by coring but not peeling and cooking by baking in an oven. Experimental studies[544] have shown that glazing (cooking in sirup) gives a more attractive and better tasting product than baking and is less expensive in equipment and labor requirements. The fruit may be cooked in a 40% sugar solution for from 6 to 18 minutes, drained, packed into enameled No. 2 cans, covered with hot 50% sirup, sealed, and cooked in boiling water for 12 minutes. The addition of small amounts of certified color, spices, or acids improves the appearance and flavor of the product. Vitamin C retention has been found to be greater in the glazed than in the baked fruit. The otherwise soft and mushy texture of baked McIntosh apples was improved by the addition of 0.05 to 0.10% calcium chloride.[545]

F. Preservation by Freezing

1. SLICED APPLES

Enzyme Inactivation. The oxidase enzyme system present in apples (Chapter V, page 83) makes some treatment necessary to

[542] D. H. Rose and H. D. Johnson, *Food Inds., 18,* 513 (1946).
[543] A. A. McCornack, C. R. Fellers, and W. A. Maclinn, *Fruit Products J., 20,* 5, 25 (1940).
[544] J. Ruffley, Jr., J. A. Clauge, and C. R. Fellers, *Canning Age, 20* (4), 68, 82, 179 (1939).
[545] C. L. Rasmussen, W. B. Esselen, Jr., and C. R. Fellers *Fruit Products J., 27,* 228, 265 (1948).

prevent the development of brown discoloration, with its associated off-flavors, during preparation, freezing, and after thawing. One of the more common methods consists of dipping the prepared fruit in a solution of sulfurous acid or one of its salts. The time of immersion depends on the concentration of sulfite used. A one- or two-minute dip in a solution containing from 2000 to 3000 parts per million is considered adequate.[546] Sulfurous acid treatment does not cause the serious leaching losses experienced when apples are scalded with steam but care must be taken to avoid excessive absorption of sulfur lest the flavor of the product be altered. Although sulfurous acid is not desirable in a food product, the small amounts necessary to prevent darkening in frozen apples have not been considered to contribute objectionable flavor to pies prepared from fruit so treated, provided care was used in preparation to avoid excessive absorption of the acid. A sulfur dioxide content of about 100 parts per million inhibits browning of fresh and frozen apple slices.

Penetration by the sulfurous acid must be complete, otherwise the slices will darken internally during storage and thawing. Because freezing stops penetration it is necessary to hold the treated fruit for from one to eight more hours before freezing, depending on the variety and condition of the apples and the temperature at which they are held. The form in which sulfur dioxide is applied also affects the rate of penetration. Sulfurous acid solutions permit rapid penetration but are objectionable to use because of their odor. Apples dipped in sulfurous acid have been reported to break up excessively during cooking.[547] Sodium bisulfite and sodium metabisulfite have been found convenient to use and give good protection from darkening, provided the fruit is held for a sufficient time before freezing to permit penetration of the sulfur dioxide. Sodium sulfite is not recommended because its alkaline reaction tends to give the product a yellow color.

Sulfurous acid solutions are prepared by passing sulfur dioxide gas into the dipping bath until the desired concentration is reached and sulfite solutions may be prepared by passing the gas into a solution containing alkali of suitable concentration or by using sulfite salts. The treating solution must be tested for sulfite content at intervals during

[546] M. A. Joslyn and E. M. Mrak, *ibid., 12,* 135 (1933). Anon., *Food Inds., 16,* 805, 862 (1944); *Food Packer, 25* (12), 56, 58, 60 (1944). M. MacArthur, *Can. Food Packer, 16* (8), 13 (1945); *Chem. Abstracts, 39,* 4406.

[547] M. MacArthur, *Can. Food Packer, 16* (4), 17 (1945); *Chem. Abstracts, 39, 3372.*

use and sulfur dioxide or a sulfite salt added to maintain its concentration. The test may be conveniently made by titrating samples of dip bath with standard iodine solution in the presence of starch. A simple, rapid test for completeness of enzyme inactivation consists of treating a freshly cut section of fruit with a 1% solution of catechol, whereupon portions of fruit still containing enzyme activity will turn black.[548] It is important in preparing apples for freezing that the pieces be of fairly uniform size since the pretreatment must be sufficient to inactivate enzymes in the center of the largest pieces.

Scalding apples in steam before freezing is also used to prevent browning. The steam may be applied to the prepared fruit as it passes through a tunnel on an endless belt. The steaming time must be sufficient to inactivate completely the enzymes in the largest pieces so they will not brown during later thawing, and care must be taken to avoid excessive softening or the fruit will break up into sauce when baked in pies. The fruit must be cooled before packaging. In order to reduce the serious leaching of sugar, acid, and flavor experienced with water cooling, air cooling has been recommended.[549] Steam-blanched fruit tends to become mushy after freezing and thawing.

Ascorbic acid and its isomers are effective in delaying discoloration during freezing, storage, and after thawing when added to sirup used in packaging to the amount of from 0.05 to 0.114% of the weight of the fruit.[550] In order to assure preservation against internal darkening it has been found necessary to obtain complete penetration by the ascorbic acid, a requirement not easily realized in commercial operations. The use of sirup in preparing frozen sliced apples is also objectionable because this product is used primarily in pies. When mixed with dry sugar and added to fruit prepared in the usual way, ascorbic acid has not been found effective.[551] By use of a special process, whereby the gases are first removed from the fruit by vacuum and replaced with liquid, or by limiting slice size to permit adequate penetration, better protection against darkening is obtained.[552] Addition of a small amount of salt to the fruit supplements the action of the

[548] J. D. Ponting, *Quick Frozen Foods, 7* (5), 31 (1944).
[549] W. V. Cruess, *Fruit Products J., 25,* 134 (1946).
[550] D. K. Tressler and C. DuBois, *Food Inds., 16,* 701, 764 (1944).
[551] M. MacArthur, *Can. Food Packer, 16* (8), 13 (1945); *Chem. Abstracts, 39,* 4406.
[552] J. C. Bauernfeind and G. F. Siemers, *Fruit Products J., 26,* 4, 27 (1946). J. C. Bauernfeind, E. G. Smith, and G. F. Siemers, *ibid., 27,* 68 (1947).

ascorbic acid and the fruit is thoroughly mixed with the sugar–ascorbic acid preparation before packaging. Special packaging methods are necessary to prevent contact of fruit with air during storage.

The use of ascorbic acid is somewhat more expensive than other pretreatments although it does not have the disadvantages of either the steam blanch or the sulfur treatment. It has been reported that the stability of ascorbic acid can be materially improved and the cost reduced by combining the ascorbic acid with citric acid.[553] The nutritive value of fruit thus fortified with ascorbic acid is unpredictable because of oxidation that may occur during storage and handling and therefore its potency cannot easily be standardized. Therefore ascorbic acid added to fruit to prevent darkening must be declared on the label as being added solely as a preservative of color.

Among other methods that have been suggested for preventing discoloration are the use of thiourea solutions,[554] subjecting the prepared fruit to a vacuum while immersed in a solution of sugar, acid, and salt,[555] and subjecting the fruit to vacuum and then pressure while submerged in a salt solution.[556,556a] Thiourea is deleterious to health and its addition to food products is not permitted under the Federal Food, Drug, and Cosmetic Act.[557] Packing apples in sugar or sugar sirups is not effective in preventing the development of brown color on thawing and the presence of sugar is not required when suitable treatments have been used. The use of invert sugar solutions to spray-freeze apples has been reported effective in preventing browning of apples by replacing the air in the fruit with sugar as well as sealing the surface.[558] Best results were obtained when the fruit was permitted to absorb about 10% of its weight of sugar sirup.

In a comparison of 5 prefreezing treatments for preservation of color in frozen Jonathan apples a sodium bisulfite dip was considered

[553] H. G. Luther and G. O. Cragwall, *Food Inds., 18,* 690, 794, 796, 798, 810 (1946).

[554] F. E. Denny, *Contribs. Boyce Thompson Inst., 7,* 55 (1935); *Chem. Abstracts, 29,* 6966.

[555] J. S. Tierney, U. S. Pat. No. 2,004,354, June 11, 1935; *Chem. Abstracts, 29,* 4851.

[556] R. A. Rasche, U. S. Pat. No. 1,877,587, Sept. 13, 1932.

[556a] H. A. Noyes, U. S. Pat. No. 2,443,866, Jan. 22, 1948; *Chem. Abstracts, 42,* 6022.

[557] *Ann. Rept. Federal Security Agency,* Section 5, Food and Drug Admin., p. 498 (1947).

[558] V. H. Greene, *Canner, 91* (14), 15 (1940).

best. Second best treatments were a potassium metabisulfite dip, vacuum treatment with an ascorbic acid solution, and vaccuum treatment with an ascorbic acid-citric acid solution. Untreated apple ranked third and apples subjected to vacuum treatment with a sodium chloride solution were considered poorest.[558a] Vacuum impregnation of apple slices with sugar sirup containing ascorbic acid or sodium bisulfite (*sirup filling*) has been found to result in a product superior in flavor to that obtained by steam blanching or treatment with a sodium bisulfite dip.[558b] Sirup filling also reduced the amount of drip obtained from the slices on thawing, prevented frothing and boiling over during baking in pies, and markedly improved the texture of soft varieties. The most satisfactory product resulted from the use of sugar solutions in the range of 40 to 60% sucrose.

Firming Treatments. The use of calcium salts to firm apple slices preserved by freezing is discussed under Canned Apples (page 300).

Packaging and Freezing. Apples may be packed for freezing either dry, with sugar, or in a sirup. For fruit to be used in baking the presence of sirup is not desirable. Dry sugar added to the product tends to draw moisture from the fruit through the action of osmosis and retards penetration of sulfurous acid when this acid is used as a pretreatment. The fruit is packed in tin containers holding up to 50 pounds of sliced fruit or in boxes or cartons suitably lined to prevent excessive loss of weight through draining and evaporation in storage. Because the slices will settle after packing it is necessary that cartons used in packaging be sufficiently rigid to support the weight of the fruit when stacked. The packaged fruit may be frozen between plates or in a blast of cold air and is stored at 0° F. or lower. Information is limited on the effect of rate of freezing and storage temperature on the quality of the product, but freezing rates in commercial operations are relatively slow because of the large size of the packages.

2. FROZEN SAUCE

Applesauce preserved by freezing is prepared in the same manner as has been described for canned sauce (page 302). Some processors dip the peeled and cored fruit in a bisulfite solution to obtain a whiter product and the shortest possible cook permitting pulping

[558a] K. G. Knight and P. C. Paul, *Food Inds., 21,* 1759 (1949).
[558b] D. G. Guadagni, *Food Technol., 3,* 404 (1949).

is usually employed to preserve the best fresh flavor. The principal problem in preparing sauce for freezing is in the precooling of the finished product before filling into containers for freezing. In some plants the prepared sauce is precooled by passing through an ammonia-jacketed tube by means of a screw conveyor. Containers commonly used in packaging frozen foods for the retail and institutional trade are satisfactory for packaging applesauce, and the storage temperature is held at 0°F. or lower.

3. FROZEN BAKED APPLES

Freshly baked apples may be preserved for relatively long storage periods by freezing. The product is prepared in the usual manner and, after cooling, is packaged in suitably lined containers for storage.[559] The addition of calcium chloride has been found to improve the texture of baked McIntosh apples (page 305).

4. DEHYDROFREEZING

An interesting experimental study of the freezing preservation of partially dried foods[560] promises to offer advantages in the commercial preservation of apples not realized by either freezing or drying alone. By this process, termed dehydrofreezing, the fruit is prepared in the usual manner for drying but evaporation is halted when about 50% of the moisture has been removed. The partially dried fruit is then frozen and handled as are frozen apples. The process has the advantage that drying is continued only during the period of rapid moisture loss and drying time is thereby greatly reduced. Removal of about 50% of the water results in a corresponding reduction in the cost of freezing, packaging, and storage as compared with fresh frozen apples. The product is convenient to use in pies as it is more easily rehydrated than dried apples and does not contain the excess liquid sometimes encountered in frozen apples. The product is more readily thawed than frozen apples because the pieces remain separate and warm water may be used in their reconstitution. Certain problems in production remain to be solved, however, before commercial development of the process can be realized.

[559] F. A. Lee, *Fruit Products J., 26,* 366 (1947).
[560] L. B. Howard and H. Campbell, *Food Inds., 18,* 674 (1946).

G. Preservation with Chemicals

1. SULFURED APPLES

In the United States temporary preservation of apples is realized by use of a sulfur dioxide treatment similar to that given apples before freezing. In population centers fresh, prepared apples are produced in centralized plants for use by nearby bakeries.[561] After preparation the fruit is treated with SO_2 solution to preserve its color. H_2SO_3 has bactericidal value and fruit prepared and treated with sulfur compounds may be held for considerable periods without spoilage. Sliced apples, when dipped for 10 minutes in a solution containing 1500 parts per million of sulfur dioxide, retained good quality for from one to two weeks when stored at room temperature (70°–75°F.) and for three weeks or longer when held at 35°F.[562] Liquid tended to drain from the fruit after storage periods of a week or longer, however. The texture of sulfured sliced apples can be firmed by the use of calcium salts (page 300). Barreled applesauce was found to require the equivalent of 0.12 to 0.15% of sulfur dioxide to prevent spoilage and it was necessary that the barrels be tightly sealed.[563]

2. BRINED APPLES

Fruits preserved in sulfurous acid solutions or solutions containing salts of this acid are used in preparing candied fruit and also for jams and preserves. In preserving apples by this method, the prepared fruit is placed in wooden barrels and covered with a 1% solution of sulfurous acid. Calcium carbonate may be added to the brine to the extent of about 6 pounds per hundred gallons to harden the fruit. The closed barrels are rotated daily for about 5 days to assure mixing of the contents and cool storage is recommended to avoid softening of the fruit and loss of sulfur dioxide. Only firm fruit is recommended for this purpose.[564] In a comparison of fruits pre-

[561] M. A. Joslyn and E. M. Mrak, *Fruit Products J., 12,* 135 (1933). W. V. Cruess and R. F. Celmer, *ibid., 18,* 43, 52, 54 (1938).

[562] W. B. Esselen, Jr., C. L. Rasmussen, and C. R. Fellers, *ibid., 27,* 276 (1948).

[563] L. B. Sosnovskii and M. A. Filyukova, *Trudy Vsesoyuz. Nauch. Issledovatel. Inst. Konditerskoi Prom., 1941, No. 3,* 273; *Chem. Abstracts,* 37, 6362.

[564] F. E. Atkinson and C. C. Strachan, *Fruit Products J., 21,* 5, 43, 60, 141, 153 (1941–42). V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1934,* 255.

served by various heat treatments and by use of sulfur compounds in sealed jars, apples preserved in sulfurous acid solutions were found to be of superior color after prolonged storage.[565] Danger from spoilage was, however, greater and flavor, texture, and pectin retention was inferior to samples preserved by heat. Little difference was observed in the effect of using solutions containing sulfur as sulfurous acid, potassium metabisulfite, or sodium metabisulfite, in the equivalent of 1000 parts per million as sulfur dioxide.

[565] A. Crang, M. Croxall, D. P. James, and M. Sturdy, *Fruit Products J.*, *25*, 143, 153, 155 (1946).

CHAPTER XII

APPLE JUICE, SIRUP, AND CONCENTRATE

A. History and Production

1. APPLE JUICE

Terminology. Fresh apple juice is subject to rapid fermentation and perhaps because of this some confusion has arisen regarding the terminology of apple juice products. In the United States the early distinction between the fresh and the fermented juice was made by simply terming the respective products as *cider* or *fresh cider*, and *hard* or *fermented cider*. The term *apple juice* was first generally used with the development of canned fruit juices. At present the term *cider* is retained for the fresh or chemically preserved product. Although the fresh product is also referred to as *apple juice* this term is usually applied to the product preserved by heat in hermetically sealed containers. In all other apple producing countries the fresh juice from apples is termed *apple juice* or *apple must* and the term cider is reserved for the fermented product. For the sake of clarity the term *apple juice* will be reserved, in this book, for the product which contains less than 0.5% alcohol, by volume, regardless of its method of preservation. Products containing more than 0.5% and less than 8% alcohol, by volume, are termed *ciders* (See Chapter XIII).

History and Production. Juice was undoubtedly one of the first products prepared from apples and until about 1930, when extensive canning of fruit juices began in the United States, was prepared and consumed in greater quantities than any other fruit juice. The early development of this product was a small-scale farm operation whereby surplus and off-grade fruit was diverted into a profitable by-product with a minimum need for costly equipment. Census figures show that 13,365,805 gallons of apple juice, then referred to as cider, were produced on 216,617 separate farms, representing every state in the union, in 1919.[566] In its early de-

[566] J. S. Caldwell, *U. S. D. A. Farmers Bull., 1264* (revised) 1938.

velopment apple juice was marketed during the fall and early winter months when fresh fruit was available. In some cases chemical preservatives, principally sodium benzoate, were added to delay fermentation but the product was generally limited to seasonal consumption.

With the development of large-scale fruit juice canning in the United States considerable attention has been directed to the preservation of apple juice by canning so that it can be marketed throughout the year. The commercial development of canned apple juice in the United States did not, however, enjoy the early rapid growth experienced by certain other juices such as tomato, pineapple, and grapefruit juice. Commercial production of canned apple juice began in 1937 but remained relatively unimportant among canned juices until about 1940 and production reached a maximum of about 2.7 million cases in the 1944–45 season, as compared with a total canned fruit and vegetable juice production of over 100 million cases in 1946–47.[567] Apple juice production in other countries, mainly in Europe, developed somewhat earlier than in the United States. Production in Germany rose from about 0.5 million Imperial gallons in 1926 to 15 million gallons in 1937. About 8 million gallons were produced in Switzerland in 1937 with smaller quantities produced in Austria, Czechoslovakia, Poland, Hungary, and England.[568]

2. SIRUPS AND CONCENTRATES

The term *juice concentrate* is usually applied to fruit juices that have been condensed by the removal of water and which, when rediluted with water, resemble the original juice in composition. Concentrated juices are usually unpalatable because of their high acid content. The term *sirup* is generally applied to products prepared from juice with the addition of sugar, or in which the acid has been neutralized sufficiently to make it palatable in a concentrated form.

The production of juice concentrates and sirups from apples was realized early in America in the production of *boiled cider*. Continued interest in these products has resulted in the application of improved methods of concentration and of methods for recovering

[567] U. S. Dept. Comm., *Industry Report, Canned Fruits and Vegetables, Production and Wholesale Distribution*. Washington, D. C., June, 1946, pp. 28–29.

[568] V. L. S. Charley and T. H. J. Harrison, *Imp. Bur. Hort. Plantation Crops, East Malling, Kent, Tech. Commun., No. 11*, 9, (1939).

volatile flavor constituents in order to retain the natural apple flavor in the concentrated products. Improvements in the quality of concentrates and sirups have been such that it is possible to prepare products that retain a characteristic apple flavor (pages 366–374). Nevertheless, commercial production is not yet extensive and statistics are not available. A possible exception is the production, begun during the war shortage of glycerin, of a bland apple sirup suitable for use as a humectant. Production estimates for this sirup indicate that between 8 and 9 million pounds were manufactured between 1942 and 1946 with production in the United States and Canada estimated at about 2 million pounds in the 1945–46 season. This product is used mainly for conditioning tobacco.

B. Apples Used for Juice

1. SOURCE

As in the preparation of other apple products the manufacturer of apple juice is limited in his selection of varieties to those available in commercial quantities as second grade or surplus from fresh market fruit. In selecting from the available varieties, considerably more leeway may be exercised than in the production of processed apples because the factor of fruit texture does not enter into the quality of the juice. Soft-fleshed varieties may, however, give difficulty in pressing after they have become mellow and mealy. Blending or mixing of juice from two or more varieties permits the use of varieties which, when used alone, would be unsuitable for juice purposes. In some sections windfalls are collected for juice purposes, care being taken that decaying fruits are removed.

Peeling and core waste from processing plants are also used in the preparation of juice. Because it is usually not possible to control the condition of this material, such juice is commonly converted into products such as sirups, brandy, or vinegar. Special attention must be given to the spray residue problem because the residue is relatively high in peel and core material (page 270).

2. VARIETIES

To prepare a product of consistently high flavor, juice from several varieties is blended to obtain the fullest aroma and the most palatable balance between the acid, sugar, aromatic, and astringent

TABLE 35. CLASSIFICATION OF APPLE VARIETIES FOR JUICE PURPOSES[a]

Acidity groups			Sub-groups		
Group I high acid	Group II medium acid	Group III low acid	Group IV aromatic	Group V astringent	Group VI neutral
Duchess	Arkansas Black	*Delicious*	Black Gilliflower	Hyslop	Alexander
Early Harvest	*Baldwin*	Fallawater	*Bonum*	Martha	*Ben Davis*
Jewett Red	*Ben Davis*	*Golden Delicious*	*Delicious*	Red Astrachan	Black Ben
Martha	Buckingham	*Rome Beauty*	Lady	Red Siberian	Buckingham
Red Astrachan	Gano	Tolman Sweet	*McIntosh*	Transcendent	Gano
Red Siberian	Golden Russet	*Winter Banana*	*Ortly*	Yellow Siberian	Missouri Pippin
Transcendent	*Greening*		Ribston		
Yellow Siberian	*Grimes Golden*		Rosbury Russet		
Yellow Transparent	Hyslop		*Snow*		
	Jonathan		*White Pearmain*		
	King David		*Winter Banana*		
	McIntosh				
	Missouri Pippin				
	Northern Spy				
	Northwest Greening				
	Ortly				
	Rome Beauty				
	Roxbury Russet				
	Spitzenburg				
	Stayman Winesap				
	Stark				
	Twenty Ounce				
	Wealthy				
	White Pearmain				
	Winesap				
	Yellow Bellflower				
	Yellow Newtown				
	York Imperial				

[a] Italicized varieties used commercially in the United States in preparing the 1946 pack.[572a] Other varieties are either not available in commercial quantities or are not available during the juice pressing season.

constituents that are principally responsible for its flavor. Several workers have classified varieties according to these qualities to serve as a guide in making the desired blend.[569, 572] Table 35 presents a classification, based on chemical composition data appearing in the literature, for a number of varieties that have been grown in the United States, showing those varieties used commercially for juice manufactured in 1946. In preparing this table varieties were placed in one of three groups on the basis of the acid content of their juice. Those varieties possessing a pronounced aroma, astringency, or lack of flavor were further classified on that basis.

3. BLENDING

Sugar–Acid Balance. The principal consideration in making a blend is acid content, and blending is used to achieve some degree of standardization of this constituent. Although varieties differ in sugar content, normal variations in this consituent do not have as pronounced an effect on flavor as do variations in acidity. Some consideration is of course given to assure that the blend does not consist primarily of juice low in sugar, or, when blends low in acid are obtained, that the juice not be exceptionally high in sugars, in order to preserve a palatable balance between these constituents. In a survey of apple juice canned commercially in the United States in 1946, the best flavor was found in juices having a Brix above 13.0°.[572a] Tentative United States standards for grades of canned apple juice,[572b] specify that Fancy juice test at least 12.5 Brix and contain not less than 0.4% and not more than 0.65% acid, calculated as malic.

Varieties normally high in acid produce an undesirably tart juice when used alone. Such juices are, however, useful for increasing the acidity of an otherwise insipid or sweet juice. Varieties that are fairly well balanced in sugar and acid are classed in Group II, Table 35, and those normally low in acid content are placed in Group III.

[569] J. S. Caldwell, *U. S. D. A. Farmers Bull., 1264,* (revised) 1938.

[570] F. W. Fabian and R. E. Marshall, *Mich. State Coll. Agr. Expt. Sta. Circ., 98* (revised) 1935.

[571] H. H. Mottern, A. M. Neubert, and C. W. Eddy, *Fruit Products J., 20,* 36, 55, 57 (1940).

[572] E. Ball, *Chemistry & Industry, 1946,* 38; *Chem. Abstracts, 40,* 2553.

[572a] M. E. Heller, T. Nold, and J. J. Willaman, *U. S. D. A. Bur. Agr. and Ind. Chem., Mimeograph,* AIC-161 (1947).

[572b] *Tentative United States Standards for Grades of Canned Apple Juice,* U. S. D. A. Prod. & Marketing Admin., Feb. 15, 1941.

Varieties listed in Group III produce a flat, insipid juice when used alone because of their high sugar–acid ratio. Most of the fruit available for juice in the United States consists of varieties listed in Groups II and III because fruit in this acid range is most desirable for fresh market use. In European countries and England the more tart culinary varieties predominate.

A rather wide variation may be found in the acidity of varieties in any group and even among different lots of the same variety because of the cultural, climatic, and maturity variations to which each variety may be subjected. A comprehensive study on the effect of climatic variations on the acidity of juice in a single growing area has shown that a given variety may vary as much as twofold in acidity from season to season.[573] Considerable variations were also noted in sugars and tannins. It therefore is necessary to determine the acid and solid content of each lot of fruit at the time of pressing in order to control these factors during blending.

Aroma. Although all apple varieties have some aroma, certain varieties are noted for having a more pronounced and pleasing aroma than others and are therefore useful in building bouquet in a juice. Varieties of this type are listed in Group IV, Table 35. Marked improvements in the quality of a blend may be realized by giving attention to the aromatic qualities of the varieties used because aroma has an important function in establishing the flavor of the juice. The bouquet can be improved by blending any of two given varieties because the aroma of a single variety does not produce as full a bouquet as that from several varieties. The use of some fruit from varieties in Group IV has, however, a distinct advantage in developing bouquet in the blend. When varieties from Group IV are also found in Group III, as is the case with Delicious, consideration is given the use of more tart varieties to compensate for the low acidity of the aromatic variety.

Astringency. The astringent quality of apple juice has been variously defined as the property of having *bite*, *body*, *tang*, *pungency*, *zest*, or *astringent aftertaste*. Many crab apples and seedling varieties have this property to such an extent that their juice is unpalatable. Such varieties are frequently rather high in acid as well. Apple varieties available for juice in the United States range from mild to moderately astringent and may be deficient in this quality, particularly after the

[573] J. S. Caldwell, *J. Agr. Research, 36,* 289 (1928).

fruit has passed prime maturity for juice purposes, or after prolonged storage. In Europe and England astringent varieties predominate but their use is confined largely to the production of fermented cider (Chap. XIII). Such varieties, when available, may be used to increase the astringent qualities of a blend. The commercial production of astringent cider varieties in the United States specifically for use in increasing the astringency of juice from dessert varieties has been suggested.[573a]

Neutral Varieties. In Group VI, Table 35, are placed some of the varieties that lack in apple flavor. Varieties lacking a pronounced and characteristic flavor are of use only to give bulk to a blend and the presence of large amounts results in a product lacking in character and flavor.

Consumer Preferences. In determining the best possible blend for juice purposes it is necessary to know the consumer preference as to acidity, aroma, and astringency. Consideration must also be given to the quantities of the different varieties available for juice. Distinct preferences have been observed regarding the most popular acidity and sugar–acid ratio for apple juice in various consuming re-

TABLE 36. Representative Acid and Sugar Content of Apple Juice in Various Countries

Country	Acid content, % malic	Soluble solids, ° Brix
United States[a]	about 0.50	13.5
Germany[b]	0.8 to 1.0	11.2 to 12.4
Switzerland[b]	0.8 to 1.0	11.2 to 12.4[c]
Holland[b]	0.7 to 0.8	11.2 to 12.4
	0.8 to 0.9	12.4 to 13.6
	0.9 to 1.1	13.6 to 17.1
England[b]	0.5 to 0.75	11.2 to 13.6

[a] H. H. Mottern, T. Nold, and J. J. Willaman, *Fruit Products J., 21,* 68 (1941).
[b] V. L. S. Charley and T. H. J. Harrison, *Imp. Bur. Hort. and Plantation Crops, East Malling, Kent, Tech. Commun. ,No. 11,* 1939; *Food, 8,* 44 (1938).
[c] Converted to degree Brix from specific gravity at 20/20°C.

gions. Table 36 presents data on what may be considered the typical or most popular juice in several of the more important apple juice consuming countries. Distinct preferences exist, however, among

[573a] F. C. Bradford, *Fruit Products J., 27,* 107 (1947).

different individuals and the ideal condition, from the consumer's standpoint, would be to market three distinct grades as is done in Holland. In producing blends of high acid content it is desirable that the sugar content be somewhat higher than is necessary for the less tart juices, to counterbalance the sharp taste.

Blending Procedure. Varieties found in Group II, Table 35, are suitable for use as basic stock, provided that they do not also appear in Groups IV, V, or VI. Even if a variety yields a juice of palatable sugar–acid ratio it is unsuitable for use as a basic stock if it lacks flavor or is highly astringent or highly aromatic. It is frequently found desirable to use two or more varieties found in Group II in preparing basic stock in order to maintain the desired acidity and also to enhance the aroma of the blend. By blending varieties in Group II advantage may be taken of the differences in acidity found among these varieties to produce a juice of more constant acidity. For example, a higher proportion of the more acid lots or varieties is frequently found desirable in seasons of abnormally low acidity, or at the end of the pressing season when the acidity decreases because of advanced maturity. In seasons of abnormally high acidity, and at the beginning of the pressing season a higher proportion of the less tart varieties may be used to advantage. When it is necessary to use considerable quantities of those varieties appearing in Group III care is taken to select the more tart varieties of Group II for basic stock in order to maintain the desired acidity, and varieties from Group I, when available, may also be used to advantage.

Small amounts of astringent varieties, when available, may be used to increase the pungency or tang of the juice, particularly when the fruit is of advanced maturity. The use of up to 10% of astringent varieties listed in Group V will have a marked effect on the flavor of the blend, whereas the use of 20% will completely alter the character of the finished product. The marketing possibilities of an astringent type of juice in the United States have not been thoroughly explored because of the lack of sufficient quantities of astringent apple varieties. The use of slightly immature fruit can also be used to increase the astringent properties of a blend if care is taken to balance such fruit with aromatic varieties so that a full flavor is obtained.

4. CONDITION OF FRUIT

Apple juice depends for its popularity on a characteristic, delicate, refreshing flavor. Precautions are observed in the selection of the fruit used, and throughout its preparation and processing, to prevent the development of off-flavors which may easily mask this delicate flavor and result in a poor quality juice. *Perhaps the most important single factor contributing to poor flavor in apple juice is the condition of the fruit used in its preparation.* It is necessary that good quality apples be used if a juice of good flavor is to result. It is imperative that the apples used be of sound quality, free from decay, and properly ripened but not overripe. The ideal condition, sometimes referred to as *cider ripe*, is slightly riper than is picked for the fresh market but while the fruit is still too firm for best eating quality.

Chemical changes occurring in apples after harvest have been discussed in Chapter VI. Of these changes the loss in acidity during storage probably exerts the most pronounced effect on the flavor of the juice, although loss of astringency and general deterioration in freshness of flavor are also important. Handling and storage conditions recommended for preserving the quality of the fresh fruit should be followed in fruit to be used for juice, and if the pressing season is to be continued into the late winter, the fruit should be stored under suitable refrigeration. Apples for juice are usually received and stored in field containers, but bin and open pile storage are employed in some areas. When bulk storage is used the pile is placed on a slatted, false floor to permit ventilation, and the fruit is covered when in danger of freezing. Care is taken to place only sound fruit in the pile and prolonged storage is not possible.

In general the quality of the fruit used for juice, other than maturity and freedom from decay, can be less perfect than is required in preparing the products discussed in Chapter XI. Bruised or otherwise damaged fruit that would require heavy trimming when prepared for drying, canning, or freezing may be used satisfactorily for juice, provided decay has not set in. Size, a limiting factor in preparing products that require peeling, is not a consideration in juice fruit. Although second grade and cull apples from the fresh fruit market offer a cheap source of raw material for juice, it is frequently difficult to control the condition of such fruit with respect to maturity and storage treatment. High quality juice is more easily attained if field-run apples are used

so that prime maturity and proper storage may be assured. The commercial development of practically every fruit juice was initially delayed through attempts to base juice production on second-grade fruit. Improved quality has been realized in each instance when the production volume increased to a point where the use of first-grade fruit became necessary to meet market demands.

Several studies have been made on the effect of various blemishes and pathological conditions found in apples on the composition and quality of juice obtained. The presence of cork, a physiological disease that seriously injures fruit quality both in appearance and texture, results in a smaller yield of juice but does not contribute off-flavors.[575] Juice from corky fruit was found to be low in acid and high in sediment. Only unfrozen apples are commonly used in the commercial manufacture of juice. Experiments have shown, however, that increased yields can be obtained from apples that have been frozen and thawed.[576] The quality of the juice was found to decrease with increasing time that the apples were held frozen. In another study[574] it was found that juices from red apples (75% of surface colored red) had a higher specific gravity, viscosity, and acidity, and were lower in tannin than juices from similar fruit with less than 50% of the surface colored red. Juices from wormy or scabby apples had a higher specific gravity than juice from similar but sound fruit, and juices obtained from large apples had a higher specific gravity than that from smaller fruits of the same lot. Apples held in cold storage yielded juices of lower viscosity than similar fruit stored at room temperature, and juices prepared from apples with stings, worm entrances, and scale lesions were higher in viscosity than those prepared from sound fruit. Juices obtained from fruit with defects were generally higher in acid and tannin than those prepared from sound fruit and as the size of the apples decreased the acidity of their juices increased. Fruit stored at room temperature yielded juices lower in tannin than similar fruit held in cold storage.

[574] J. Forgacs, W. A. Ruth, and F. W. Tanner, *Food Research, 10,* 227 (1945).
[575] L. R. Tucker, *Fruit Products J., 20,* 343 (1941).
[576] S. F. Tserevitinov, *Kholodil'naya Prom., 16,* (5), 41 (1938); *Chem. Abstracts 33,* 8844.

C. Juice Preparation

1. PREPARATION OF APPLES

Inspection and Washing. Apples to be used for juice are inspected and if in poor condition are sorted to remove decayed and badly damaged fruit. When economical, small decayed spots may be removed by trimming provided care is taken to remove all decayed flesh. The fruit is thoroughly washed not only to remove visible dirt but also to reduce the number of microorganisms on the surface. By thus reducing the initial inoculation of the juice with organisms greater stability to fermentation is obtained during processing and the quality of the juice is improved. Washers may incorporate a preliminary soaking tank followed by spraying in a rotating cylindrical washer. Advantage has been found in using high-pressure water sprays in the cylinder which mechanically blow off dirt and decayed material.

Spray Residue Removal. Spray residue is not a problem in juice when the apples used are near the tolerance permitted for fresh fruit. When apples contain borderline amounts of lead and arsenic, the resulting juices have been found to be far below the tolerance.[577] When the juice is to be used in preparing concentrates, or when the pomace is to be used for feed or food products from which the spray residue is not removed during processing, it is advisable to subject the fruit to a hot acid or alkaline wash before processing to reduce the residue to a minimum. Removal of the stem and core ends of washed fruit will also markedly decrease the residue in the pomace.

2. GRINDING (MILLING)

To obtain the maximum yield of juice it is necessary to disintegrate the apple tissues and mechanically disrupt as many individual cells as possible. Studies on the effect of fineness of milling[578-580] indicate that the most thorough disintegration of the tissues gives the best quality and yield of juice. Flavor constituents and vitamins concentrated directly beneath the skin are more completely expressed after thorough disintegration, and grating has been reported to produce

[577] H. H. Mottern, A. M. Neubert, and P. D. Isham, *Wash. Agr. Expt. Sta., 48th Ann. Rept., Bull.,* 368, 1938, pp. 94–95.
[578] A. Mehlitz, *Süssmost.* Serger und Hempel, Braunschweig, 1938.
[579] V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta. Long Ashton. Bristol, 1937,* 160 (1938).
[580] G. Warcollier, *Le cidrerie.* Bailliére, Paris, 1928.

a juice richer in ascorbic acid than crushing.[581] If ground too fine, however, some difficulty may be experienced because of pulp passing into the juice during pressing.

Roller Mills. Several types of grinders or mills are used in crushing apples for juice. The oldest method consists of crushing the

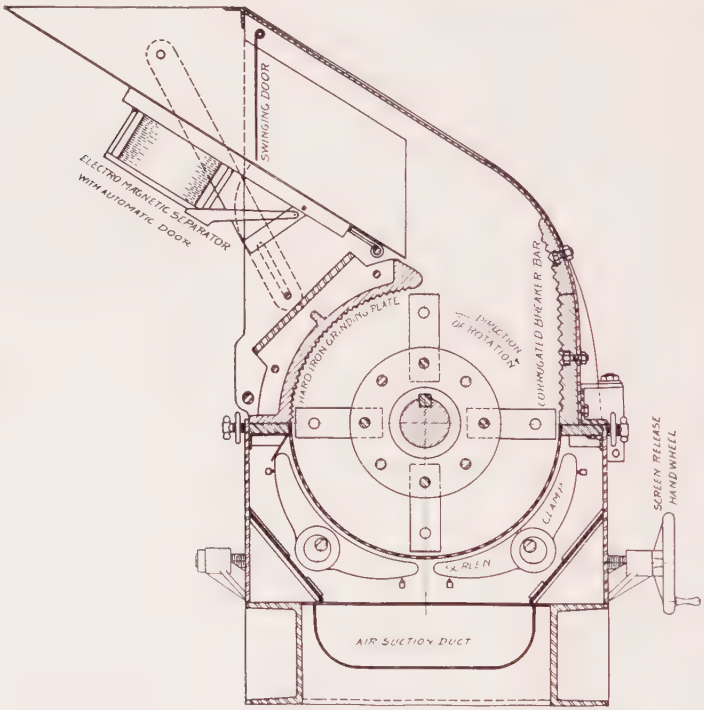


Fig. 74. Sectional view of a hammer mill.[581a]

fruit between stone rollers. This method is said to be very effective in disrupting the fruit cells, including the seeds, but its use is now confined to European countries because of the low capacity of such mills.

Grater Mills. Mills operating on a grater principle are widely used in preparing apples for pressing. Short knives, set in a steel cylinder, work against an adjustable corrugated plate. As the fruit

[581] J. Tavernier and P. Jacquin, *Bull. assoc. chim., 63,* 111 (1946); *Chem. Abstracts, 41,* 1048.

[581a] A. E. Abrahamson, in M. B. Jacobs, ed., Food and Food Products, Vol. II. Interscience, New York, 1944, p. 179.

falls on the rapidly rotating cylinder the knives grate it until the remaining pieces are sufficiently small to pass between the cylinder and the plate. The fineness of grating can be regulated somewhat by adjusting the clearance between the cylinder and the concave plate. A frame, wooden hopper, and pulp bin or chute complete the unit. Graters are available in a wide range of capacities and the larger units are power driven.

Hammer Mills. More recently hammer mills, of both the horizontal and the vertical disintegrator types, have been adopted for crushing apples. Heavy beaters, mounted on a revolving shaft, just clear a heavy, concave perforated plate or cylinder. The shaft and beaters are mounted on a frame and are enclosed by a hopper and pulp bin or chute. Fruit falling on the beaters is shattered in midair and is held within the mill until ground sufficiently fine to pass through the perforated plate. The fineness of grinding can be regulated by the speed of the mill. Higher yields of juice are obtained with hammer mills than with other types. Stainless-steel construction has not been found necessary for mills as very little metal is acquired by the pulp and no deterioration in juice quality has been traced to this source.

3. MACERATION

Maceration consists of holding the milled fruit for a period of 12 or more hours before pressing. The process has been employed extensively in Europe and England in the manufacture of fermented ciders to obtain a fuller, more pronounced fruit flavor (page 384), but is not employed in the commercial manufacture of unfermented apple juice. In experimental studies on English varieties[582] it was found that maceration for 12 hours resulted in a more fully flavored juice, but a harsh aftertaste made it less desirable than the control sample. A generally improved flavor was obtained, however, by the macerating for 24 hours of 35 to 40 pounds of presscake per 100 gallons of juice.

4. PRESSING

Barrel Presses. Several types of presses are used to remove the juice from the pulp. For small, farm operations hand-operated barrel presses are still widely used. They consist of a cylinder constructed of wooden slats placed on a slatted frame and supplied with a solid piston. The ground fruit is placed in the barrel and pressure applied to the

[582] V. L. S. Charley, *Fruit Products J., 18,* 268 (1939).

fruit by the piston by means of a hand-operated screw or a hydraulic press. Yields obtained with the barrel press are low and capacities, even when equipped with power-driven hydraulic rams, are not as great as with the rack-and-cloth system.

Rack-and-Cloth Presses. The rack-and-cloth system of holding the pulp is the most widely used method in commercial use. The racks consist of wooden slats from 1 to 2 inches wide and about 0.25 inch thick, mounted in two layers at right angles to each other with about

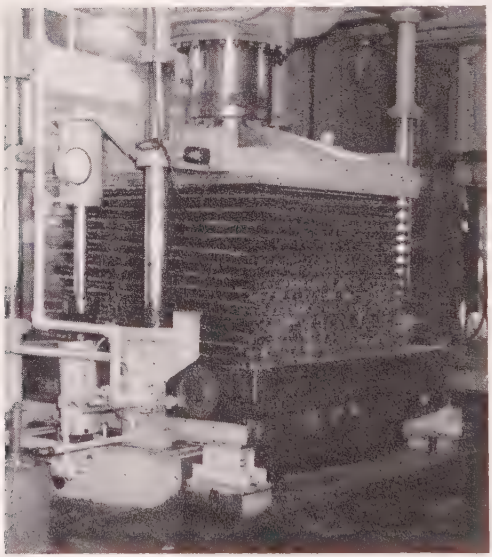


Fig. 75. Inverted ram hydraulic press capable of handling two tons of ground apples per pressing. Cheeses are built under chute shown in upper right. Apples are milled on second floor above chute.

0.5 inch spaces between the slats in each layer. Tough, pliable hardwoods, free from resins that might impart flavor to the juice, are used and the slats are fastened with corrosion-resistant nails. Cloths may be of heavy cotton, nylon, or wool, cut in squares about 1.5 times the size of the racks.

To prepare the pulp for pressing it is placed in the cloths and spread evenly in a layer from 2 to 3 inches deep within a form that is from 2 to 3 inches smaller than the rack. The cloths are laid in the form with the corners diagonal to those of the racks and, after filling, these corners are folded over the pulp so that it is held in a cloth envelope. These envelopes of pulp, called *cheeses,* are built one on top

of the other and separated by racks. The completed pile of cheeses is then placed in a hydraulic press which expresses the juice.

Hydraulic Presses. With the exception of small home presses, which usually operate by means of a screw, practically all apple juice is pressed with power-driven hydraulic presses, which vary in size and style. The ram may be placed under the cheeses which are then raised against a stationary plate, or the ram may be inverted and exert a downward pressure on the cheeses as they rest on a base equipped with troughs for collecting the juice. Sizes are usually denoted in terms of tons of pressure exerted by the ram. The larger presses are constructed to handle larger racks and cheeses, so that the pressure per square inch of pulp remains the same. Pressures exerted per square inch of cheese vary from 100 to over 250 pounds per square inch. By reducing the size of the cheeses the pressure exerted per square inch for a given ram can be increased. The time required to complete the pressing is thereby shortened and the yield may be increased, but smaller amounts of pulp are handled in each pressing.

Pressing Operation. The most common procedure for pressing juice consists in making a single pressing, after which the cheeses are removed and the pomace separated from the cloths. In some cases it has been found economical to press, in two stages. The cheeses are first pressed in a large, low-pressure press which removes the greatest portion of the juice, after which the partly pressed cheeses are transferred to a smaller, high-pressure press to complete the operation. Under certain conditions it is advantageous to disintegrate and repress the pomace to effect an increase in yield of juice. This procedure is more common when low-pressure presses are used. To accomplish a second pressing the once-pressed pomace is disintegrated in a pomace picker and used in building new cheese. In some cases even a third pressing may be made. With normal operation, the average yield that can be expected with three pressings are 150, 20, and 3 gallons per ton of fruit. After the pressing is completed the racks and cheeses are removed from the press and the cloth stripped from the pomace. The pomace is usually passed through a pomace picker and transferred to storage bins for further processing (Chapter XV).

Pressing Room Arrangement. Pressing is a batch operation requiring considerable hard manual labor in building the cheeses, moving them to the press, and then stripping the pressed pomace from the cloths. The efficiency of the operation therefore depends to a con-

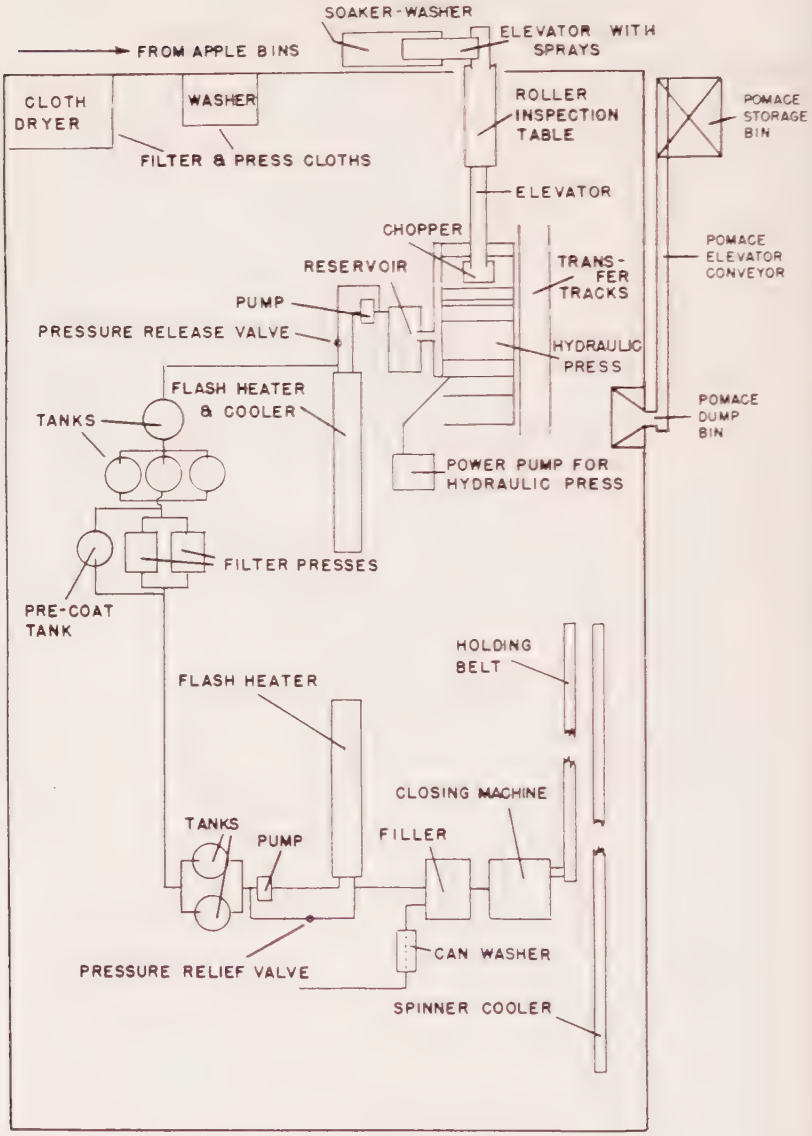


Fig. 76. A floor plan for the preparation and processing of apple juice.[552a] Clarification by heat treatment and filtration is indicated.

[552a] R. E. Marshall, *Mich. State College Agr. Expt. Sta. Circ. Bull.*, 206, June 1947.

siderable extent on the convenience of arrangement of the various pieces of equipment. Transfer of the cheeses and other equipment is usually accomplished on small carts running on tracks built into the pressing room floor. Automatic pulp dumpers may be used to lighten the work of building cheeses.

Utmost cleanliness is required in operating a press room to assure that undesirable, off-flavors are not imparted to the juice. Besides frequent washing of the equipment to remove accumulated pulp and spilled juice, special attention is given to the cloths and racks. Unless it is periodically washed and aired this equipment tends to impart a musty, stale flavor to the juice.

Continuous Presses. Numerous attempts have been made, without success, to adapt continuous presses to the manufacture of apple juice. A continuous juicer of the disintegrator type used in preparing pineapple juice has been successfully applied to apples but produces a pulpy product unlike conventional apple juice in color or flavor. The process consists of feeding washed, whole, or chopped apples into a comminution machine which is equipped with special screens having very small holes. The more finely divided pulp passes through the screens with the juice and the coarser material is ejected as waste. The machines have a very high capacity. The comminution area is enclosed and can be operated in an atmosphere of inert gas. By passing the juice directly to a deaerator and pasteurizer the enzymic darkening characteristic of the conventional juice can be avoided. The amount of pulp incorporated into the juice is dependent on the condition of the fruit and can be varied by adjustment of the machine. It is common to prepare juice containing from 15 to 18% of suspended solids by this process.

5. NATURE OF FRESHLY PRESSED JUICE

Color. Apple juice flows from the press as an amber fluid that may darken slightly within a few minutes after pressing. This amber color has always been associated with apple juice and, although the sap in the apple is colorless or straw colored, consumer habits are such that considerable effort would be required to change their preference to a product having a natural apple sap color. The change in color during pressing is caused by enzymic oxidation of tannin compounds present in the juice. (Chapter V, page 83.) The nature of conventional apple presses and delays inherent in methods of pressing the

pulped fruit make it impossible to retain the natural color of the apple sap unless special processes are used.

A procedure for retaining the natural apple color and flavor in the juice by the use of ascorbic acid has just been developed by Pederson, Holgate, and Moyer.[583] Chilled apples are rapidly ground and an apple juice solution of ascorbic acid is sprayed on the pomace during milling at a rate equivalent to from 6 to 12 grams of ascorbic acid per bushel of apples (40–45 lbs.). After pressing the juice is deaerated, flash pasteurized, and sealed into containers as rapidly as possible to avoid darkening. Special care must be used to avoid contamination of pulp or juice with iron or copper. Laboratory-scale studies have shown that light-colored juice may be prepared by pulping apples in an atmosphere of nitrogen or carbon dioxide gas.[583a] Nitrogen was preferred to carbon dioxide and the addition of a small amount of ascorbic acid (2 grams per bushel) to the milled pulp aided in retaining a light color during delays between pulping and pressing or in processing the juice. Commercial application of this development would require modification of milling equipment to provide a gas-tight milling chamber. The crushed pulp may also be treated chemically, as with sulfur dioxide, before pressing or the pressed juice may be treated with sulfur dioxide to yield a light-colored juice. Treatment with thiourea has been found to produce light-colored juice[583b] but this chemical is not suitable for use in food products because of its toxicity (page 308).

Suspended Solids. Beside soluble constituents responsible for its flavor, aroma, and color, freshly pressed juice also contains more or less suspended solids ranging in size from lumps, through cellular pulp, to finely divided, dispersed colloidal material. The larger pieces are usually removed from the juice by screening at the press. Table 37 shows the composition of the suspended solids removed from apple juice by centrifuging. These data indicate the mucilaginous, hydrophilic nature of the suspended material, as protein and pectic substances are the principal constituents. A comparison of the suspended solids of juice prepared from Styrian apples with the water-insoluble residue

[583] C. S. Pederson, *Fruit Products J., 26,* 294, 313 (1947). K. C. Holgate, J. C. Moyer, and C. S. Pederson, *ibid., 28,* 100, 112 (1948).

[583a] G. F. Chambers, *Food Inds., 22,* 88 (1950). F. E. Atkinson and C. C. Strachan, *Food Technol., 4,* 133 (1950).

[583b] F. E. Denny, *Contribs. Boyce Thompson Inst., 7,* 55 (1935); *Chem. Abstracts, 29,* 6966.

from the pomace showed the former to contain 2.4% crude fiber and 2.6% uronic acid as contrasted with 24.5 and 19.3%, respectively, of the same constituents in the residual pomace. On the other hand, the phosphorus content of the ash from the suspended solids was 43.4%

TABLE 37. Composition of Centrifuged Material from Apple Juice[a]

Composition, %	Northern Spy	Rome Beauty	Russet
Dry material, grams[b]	22.00	37.40	43.30
Ash	2.80	4.85	5.50
Fiber	4.24	2.66	2.80
Protein (N × 6.25)	19.05	30.70	24.75
Protopectin[c]	1.58	3.64	2.72
Pectic material[d]	33.02	24.00	22.80
Tannin	1.58	1.46	0.96
Ether extract	8.19	6.57	5.06
Total sugars	11.60	3.84	2.91
Total	*82.06*	*77.72*	*67.50*

[a] D. C. Carpenter and W. F. Walsh, *N. Y. Agr. Expt. Sta. Tech. Bull.*, 202, 1932.
[b] Centrifuged material was obtained in all cases from 5 gallons of raw juice and dried to constant weight at 102°C.
[c] Protopectin (pectose) extracted by *M*/75 HCl and reported as calcium pectate.
[d] Pectic material extracted by *M*/75 NaOH and reported as calcium pectate.

(as P_2O_5 in the SiO_2-free ash) as contrasted with 19.3% in the case of the pomace. The protein content of the suspended solids was 19.3% and that of the pomace 5.6%.[584] Differences were also observed in the character of the lipid fraction.

D. Juice Processing

Considerable quantities of apple juice are consumed in the cloudy condition in which it flows from the press. In order to reduce the amount of unsightly sediment which forms in the bottom of the containers on standing the juice is usually held in deep tanks for a short time to permit settling. The juice is then siphoned from the sediment and may be bottled for immediate market or further processed and preserved. Removal of excess cellular material may also be accomplished by passing the juice through a centrifuge. By employing a

[584] E. Letzig, *Z. Lebensm. Untersuch. u. Forsch.*, *88*, 39 (1948).

centrifugal force of about 9,000 times that of gravity a cloudy juice can be obtained that will remain practically free from sediment during normal market life. When a cloudy juice is to be preserved by heat in hermetically sealed containers it is necessary to give it a preliminary heat treatment to permit removal of substances that may be coagulated by heat. Heat-treated juices are more turbid than fresh, unheated juice.

1. CLARIFICATION

Recent trends in the preference for a clear preserved apple juice as well as for a clear fresh juice have resulted in an enormous increase in the production of juice free from suspended material. Removal of suspended solids by direct filtration is difficult because of mucilaginous, hydrophilic gums and pectinous materials contained in the freshly pressed juice. Much of the suspended solids are colloidal and retentive filters are required to produce a clear product. Furthermore, the capacity of such filters is limited because of rapid clogging with suspended and hydrophilic matter. It therefore simplifies the filtration operation if the juice is subjected to a clarification treatment capable of disrupting the colloidal system to produce an easily filterable juice that will be clear as it flows from the filter.

Numerous processes have been developed to accomplish clarification of apple juice. All involve a breaking up of the colloidal system, either through chemical or mechanical action. To be practical the clarification treatment must be fairly rapid so that fermentation will not take place during treatment; it must be easily and reliably accomplished, and it must not detract from the quality of the juice or add an off-flavor to the product.

Enzyme Clarification. A number of enzyme preparations have been employed to clarify apple juice. Their action depends on their ability to hydrolyze colloidally suspended material into either more or less soluble substances. In either case these substances lose their hydrophilic, colloidal properties and thereby disturb the colloidal system in the juice. It is not always necessary that all of the colloidally suspended materials present in the juice be decomposed in order to effect clarification. Many substances of colloidal nature act to protect or stabilize other suspended material, and when the colloidal stability of the system is disrupted by an attack on one substance the rest may then be readily removed.

Enzyme preparations that have been used for clarifying apple

juice usually have contained several specific enzymes, each of which may attack some colloidally suspended material. Early investigations included the use of protein- and starch-splitting enzymes.[585, 587] Although these enzymes materially accelerate filtration they have not been found sufficiently effective to produce an economically filterable juice. This is probably due to the fact that starch and protein substances are only minor constituents of apple juice.

Pectic materials are important colloidal substances present in apple juice. Early studies by French cider makers[588] indicated that coagulation of the pectins of apple juice, immediately after pressing is an essential step in the making of high-grade clear ciders. The coagulation of pectinous materials by these early workers was effected by holding the juice at reduced temperatures while natural decomposition of the pectins took place. The process was found to be accelerated by the additions of certain salts including sodium or potassium carbonate, calcium sulfate, potassium metabisulfite, and sodium chloride.[589] Temperatures of storage recommended varied from 32° to 54°F. and the time required for clarification to take place varied from 12 hours to as much as six weeks. In one process the natural decomposition of the pectinous material was augmented by the use of protein-splitting enzymes[590] obtained from plants selected from the group *Bromeliaceae* and *Caricaceae*. In general these procedures have not been found commercially economical or sufficiently reliable in their action, in part because of the wide variations between juices in their natural pectin content and in their ability to hydrolyze pectinous material. The addition of salts frequently results in a deleterious effect on flavor and the time element involved makes it necessary to have large refrigerated storage facilities on hand during the pressing season. Incipient fermentation tends to detract from the flavor of the juice and unless great care is taken active fermentation results. Natural pectin-splitting enzyme extracts have been prepared from certain plant juices to hasten clarification.

The addition of pectin-decomposing enzyme preparations to apple

[585] S. A. Waksman, *Canner, 54* (18), 45 (April 29, 1922).
[588] M. L. Daughters, *Canning Age, 8,* 503 (1927).
[587] E. R. Darling, U. S. Pat. No. 1,659,086, Feb. 14, 1928; *Chem. Abstracts, 22,* 1416.
[588] G. Warcollier, *Ann. brass. Dist., 15, 237* (1912).
[589] J. S. Caldwell, *U. S. D. A. Bull.,* 1025, (1922).
[590] E. Schoop, U. S. Pat. No. 2,082,426, June 1, 1937.

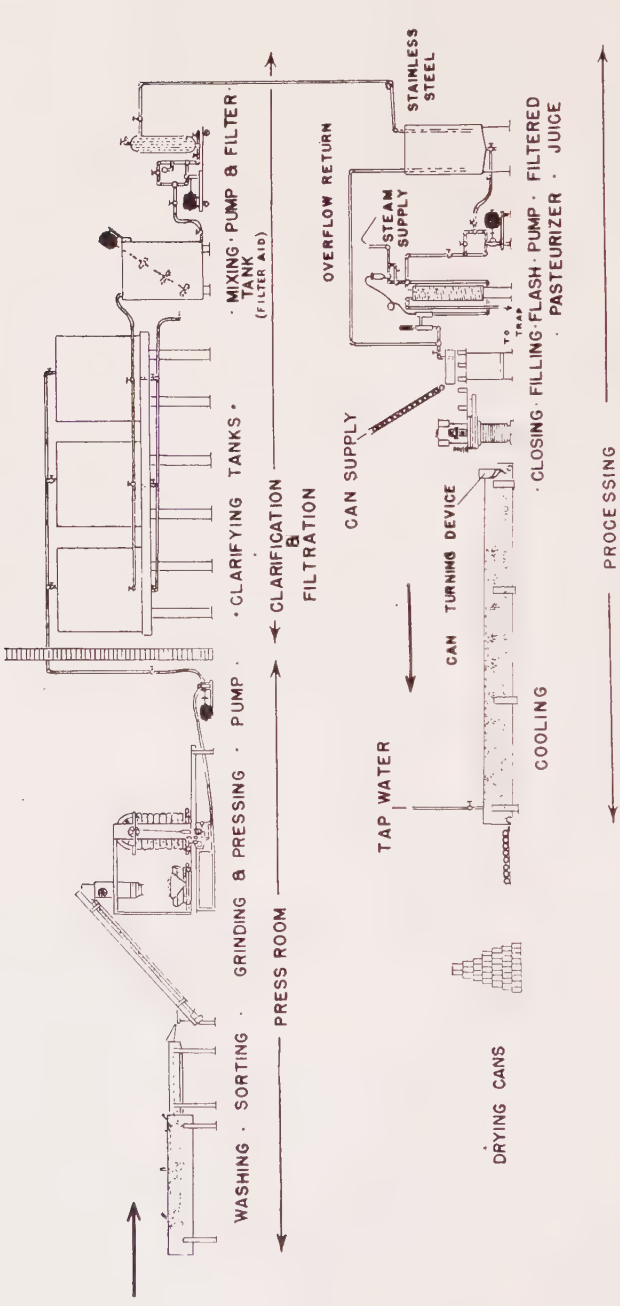

WASHING · SORTING · GRINDING & PRESSING · PUMP · CLARIFYING TANKS · MIXING · PUMP & FILTER TANK (FILTER AID)
PRESS ROOM
CLARIFICATION & FILTRATION
OVERFLOW RETURN
STAINLESS STEEL
STEAM SUPPLY
CAN SUPPLY
TAP WATER
CAN TURNING DEVICE
DRYING CANS
COOLING
CLOSING · FILLING · FLASH · PUMP · FILTERED JUICE · PASTEURIZER
PROCESSING

Fig. 77. Flow diagram of the preparation and processing of enzymic clarified apple juice.[562a] Stainless-steel tanks, pipes, and equipment are recommended for handling apple juice.

juice has proven the most effective means for clarification and is perhaps the most widely used process today. The preparations may be obtained from various molds including *Aspergillus oryzae*, *A. aureus Nakazawa*, and *Penicillium glaucum* when grown on proper nutrient medium.[591-595] These preparations contain enzymes capable of splitting the methyl group from pectin, *pectin esterase* (pectin methylesterase, pectase), and also of breaking the glycosidal linkage between galacturonic acid units, *pectin polygalacturonase* (pectinase).[596,597] Enzyme action results in progressive hydrolysis of pectinic acids, accompanied by deesterification. Ultimate end products of decomposition are D-galacturonic acid and methyl alcohol. There is little doubt that at least some of the nonpolyuronide hemicelluloses which accompany the pectin substances in apples are also attacked by the clarifying enzymes. Optimal acidity for polygalacturonase is about *p*H 3.5 whereas esterase obtained from fungal preparations has greatest activity at about *p*H 4.5 but is still very active in the range *p*H 3.0 to 3.5.

Commercial preparations of these enzymes, available in the United States as Pectinol and in Germany as Filtragol,[598,599] are sufficiently potent to permit the rapid handling of large quantities of juice, at the same time requiring little skill on the part of the operator. Gelatin is usually added to these preparations to facilitate precipitation and stabilize the enzymes in solutions. Results are reliable and the colloidal system of the juice is so completely broken down that the juice may be rapidly filtered without difficulty from clogging. A brilliantly clear juice can be obtained even when porous filter mediums are used. The time required for clarification varies from a few hours to several days, depending on the quantity and potency of the preparation used and the temperature of the juice. These factors may be varied by the processor to meet his specific requirements.

[591] A. Mehlitz, *Konserven-Ind., 1930,* 306, 321; *Chem. Abstracts, 25,* 153. A. Mehlitz, *Konserven-Ind., 1930,* 742, 756; *Chem. Abstracts, 25,* 1601.
[592] J. J. Willaman, *Minnesota Studies in Biol. Sci.,* No. 6, 1937.
[593] Z. I. Kertesz, *N. Y. Agr. Expt. Sta. Bull.,* 589, 1930.
[594] N. V. Novotel'nov and R. I. Barkowskaya, *Proc. Inst. Sci. Research Food Ind. U. S. S. R., 3* (3), 5 (1935); *Chem. Abstracts, 30,* 4941.
[595] J. J. Willaman and Z. I. Kertesz, *N. Y. Agr. Expt. Sta. Tech. Bull.,* 178, 1931.
[596] Z. I. Kertesz, *J. Biol. Chem., 121,* 589 (1937).
[597] H. H. Mottern, A. M. Neubert, and C. W. Eddy, *Fruit Products J., 20,* 36, 55, 57 (1940).
[598] A. Mehlitz, German Pat. No. 680,602, 1933.
[599] J. J. Willaman and Z. I. Kertesz, U. S. Pat. No. 1,932,833, Oct. 31, 1933.

Colloidal Precipitation. Removal of colloidal material by the addition of precipitating agents has long been practiced in the clarification of wines, vinegars, fruit juices, and other sugar solutions. The process depends on disturbing the electrical charge present on colloidally dispersed material which acts to stabilize its dispersion. Gelatin is one of the most commonly used agents to precipitate colloidal material from fruit juice and, when used in conjunction with tannin, is probably the most effective precipitating agent in use for clarifying apple juice.

Colloidal material dispersed in apple juice is negatively charged. When a dispersion of positively charged gelatin is added the oppositely charged particles coalesce and precipitate, carrying down with them the suspended solids. Because tannin, in varying amounts, is a natural constituent of apple juice it is necessary to make clarification trials on each lot of juice to determine the proportions of each agent needed for the best results.[600] The process requires considerable skill and results are not always reliable. When properly conducted the treatment yields a readily filterable juice that is brilliantly clear, although the precipitate is somewhat voluminous and may require the discarding of considerable quantities of juice in the sludge. Use of a water-soluble alginate for clarifying apple juice has also been proposed.[601] A water solution of alginate is added to the juice and a reagent such as lime, sulfuric acid, or phosphoric acid is then added to the precipitate of calcium alginate or alginic acid, thereby carrying down suspended solids in the juice.

The colloidal material may also be precipitated by the addition of a dispersion of a finely divided, insoluble, colloidal agent such as Spanish clay, fuller's earth, bentonite, or carbon. As these materials settle through the juice the particles tend to absorb colloidal material and carry it down, leaving a clear supernatant juice. Clarification is usually not as complete as with enzyme treatment and a retentive filter is required to remove the finely divided material that has been added. As with the gelatin–tannin treatment, considerable amounts of juice are lost in the sludge. Activated carbon is unsatisfactory as a clarifying agent because of its adverse effect on color and flavor.[602]

Chemical Clarification. Chemical agents capable of destroying the colloidal suspension in apple juice are not suitable when the prod-

[600] D. C. Carpenter and W. F. Walsh, *N. Y. Agr. Expt. Sta. Tech. Bull.*, 202, 1932.

[601] E. Ricard, Brit. Pat. 173,735, Sept. 20, 1921; U. S. Pat. No. 1,515,968, Nov. 18, 1924; *Chem. Abstracts, 19,* 365.

[602] J. S. Caldwell, *U. S. D. A. Bull.*, 1025, 1922.

uct is to be consumed as a fruit juice because of adverse effects caused by these treatments on the flavor. Chemical treatment has been found adaptable in the preparation of sirups in which natural acidity and flavor are not requirements of the finished product (page 375). Clarification is effectively accomplished by raising the *p*H of the juice until it is slightly alkaline, whereby pectin in the juice is hydrolyzed to insoluble pectic acid. In one process the pectin material in apple juice is converted into insoluble calcium pectate by raising the *p*H to about 8.5 with calcium hydroxide and holding the alkaline solution at a temperature of about 175° F. for a short time.[603,604] The treatment yields a readily filterable solution which requires acidification before further processing. Calcium salts of malic acid, which are formed during this process, are bitter and it is therefore necessary to subject neutralized juice to special processes which remove the calcium in order to make them palatable.[605]

Heat Treatment. A process involving the flash-heating of apple juice to 180° F. for about 20 seconds, followed by rapid cooling, has been proposed as a means of clarifying and improving the filterability of apple juice.[606] In a more recent study[607] flash-heating was found to be particularly effective in clarifying apple juice. Juice clarified in this way was considered superior in flavor to juice clarified by means of enzymes or bentonite and showed no tendency to deposit a sediment. The chemistry involved in the coagulation of colloidal juice constituents by heat is not well understood, but heat treatment frequently increases the turbidity of apple juice. Some apple juices, previously filtered to a clear condition without preliminary treatment of any sort, will become turbid when heated and cooled.

As a means of producing an economically filterable juice, heat treatment should be considered only after experimental tests on the juice at hand have demonstrated its practicability. Filtration difficulties have been observed to increase after heat treatment in the case of many juices, and unless a very retentive filter medium is used the product is apt to be hazy. Differences observed in various lots of juice, in their

[603] M. A. Bradshaw and H. H. Mottern, *U. S. D. A. Pub.*, ACE 180; *Fruit Products J., 21,* 356 (1942).
[604] H. H. Mottern and R. H. Morris, III, *U. S. D. A. Pub.*, AIC-37, 1944; *Fruit Products J., 23,* 261, 283 (1944).
[605] R. E. Buck and H. H. Mottern, *Ind. Eng. Chem., 37,* 635 (1945).
[606] D. C. Carpenter and W. F. Walsh, *N. Y. Agr. Expt. Sta. Tech. Bull.,* 202 1932.
[607] W. B. Esselen, Jr., *Fruit Products J., 24,* 165, 189 (1945).

TABLE 38. EFFECT OF ENZYME CLARIFICATION ON APPLE JUICE[610]

Juice source	Blend of Winesap and Delicious juice		Jonathan juice		Winesap juice		Delicious juice	
Juice treatment	Untreated[a]	Pectinol clarified[a]	Untreated[b]	Pectinol clarified[b]	Untreated[b]	Pectinol clarified[b]	Untreated[b]	Pectinol clarified[b]
Specific gravity, 15/15°C	1.0580	1.0585	1.0573	1.0573	1.0599	1.0601	1.0642	1.0646
Refractive index, 20°C	1.3541	1.3544	1.3538	1.3538	1.3549	1.3551	1.3564	1.3568
Soluble solids, % (calc. from R. I.)	14.0	14.2	13.8	13.8	14.5	14.6	15.5	15.7
Reducing sugars (as invert), %	10.07	10.33	9.80	10.04	10.79	11.06	11.49	11.79
Total sugars (as invert), %	12.34	12.44	11.69	11.77	12.09	12.10	13.43	13.61
Sucrose, %	2.16	2.00	1.80	1.64	1.23	0.98	1.85	1.74
Total acid (as malic), %	0.451	0.460	0.449	0.454	0.483	0.488	0.205	0.210
*p*H (glass electrode)	3.58	3.56	3.56	3.52	3.59	3.57	4.02	4.00
Alcohol precipitate, %	0.109	0.069	0.093	0.054	—	—	—	—
Pectic acid, %	0.079	0.021	0.066	0.009	—	—	—	—
Viscosity, centipoise	2.591	1.536	2.391	1.503	3.416	1.579	1.633	1.597
Nontannin astringency (as tannin), %	0.032	0.032	—	—	—	—	0.037	0.036
Tannin, %	0.043	0.035	—	—	—	—	0.038	0.036
Total astringency (as tannin), %	0.075	0.067	0.025	0.027	0.075	0.076	0.074	0.073
Ash, %	0.274	0.273	—	—	—	—	—	—
Protein, %	0.019	0.019	—	—	—	—	—	—

[a] Filtered through duck.

[b] Filtered through Whatman No. 2 paper.

response to heat treatment, may be attributed in part at least to differences in the physiological condition of the fruit at the time of pressing. Improvement in filterability and clarity results when heat treatment is combined with a colloidal precipitant such as bentonite; this combination process has given satisfactory results under commercial conditions.[608]

Effect of Clarification on Juice Quality. A preference has been shown for clear apple juice but the consumer is usually very critical of changes caused in the juice as a result of the clarification process. The delicate, mild flavor of the juice makes clarification without change in flavor difficult. All materials used in processing the juice, including supposedly inert inorganic filter mediums, are carefully checked before use to assure that they have not absorbed off-flavors during preparation, shipment, or storage that might later be imparted to the juice. Several investigators have studied the chemical changes occurring in juice as a result of clarification and filtration treatments.[606,-609-611] Although some workers believe that the suspended solids in freshly pressed apple juice contribute a flavor to the product which is lost by clarification, it is probable that these changes are largely due to alteration of the physical properties of the juice by decrease in body or viscosity. Of course this holds only if no extraneous flavor is added during the clarification process. The removal of suspended solids has a distinct advantage from the standpoint of retention of a fresh, natural apple flavor, in the case of juice that is preserved by heat. Cloudy juice tends to develop a cooked flavor more readily than clarified juice and heat causes an increased turbidity that is considerably less appealing than that of the raw, unheated juice.

The effect of enzyme treatment on apple juice varies with the preparations used. Off-flavors may be contributed to the juice unless the enzyme preparation is freed from such flavors during manufacture. In general, commercial preparations of pectin-decomposing enzymes are now available that do not contribute noticeable flavor and their

[606] H. L. Sipple, G. H. McDonell, and R. H. Lueck, *Fruit Products J., 19,* 167, 180, 187 (1940).

[609] J. A. Clague and C. R. Fellers, *Mass. Agr. Expt. Sta. Bull.,* 336, 1936.

[610] A. M. Neubert, *A Study of the Effect of Filtration, Clarification, and Concentration on the Composition and Properties of Apple Juice.* Thesis, State College of Washington, 1941.

[611] H. Le Corvaisier, *Chimie & industrie, 56,* 382 (1946); *Chem. Abstracts, 41,* 2816.

TABLE 39. EFFECT OF CLARIFICATION TREATMENTS ON APPLE JUICE[610]

Treatment	Juice description	Brix at 20°C.	Total acidity,[a] %	Non-tannin astringency,[b] %	Tannin, %	Total astringency,[b] %	Alcohol ppt., %	Pectic acid, %	Viscosity, centipoise
Pressed from 8 Parts Winesap and 3 Parts Delicious Apples									
Clarified samples filtered through Whatman No. 2 filter paper using Filteraid									
Gelatin-tannin clarified	Clear	13.58	0.36	0.022	0.021	0.043	0.057	0.019	1.670
Flash-heated to 89°C. and cooled	Slightly cloudy	13.75	0.36	0.022	0.025	0.046	0.057	0.031	1.727
Pressed from Winesap Apples									
Flash-heated to 89°C. and cooled. Submitted to centrifugal force of:[c]									
9,500 G	Turbid	13.90	0.41	0.033	0.035	0.068	0.054	0.018	1.745
19,400 G	Turbid	—	—	—	—	—	0.053	0.019	1.714
31,000 G	Turbid	—	—	—	—	—	0.050	0.017	1.706
Gelatin-tannin clarified. Filtered through Seitz K2 filter	Clear	—	—	0.031	0.016	0.047	0.043	0.013	1.655
Enzyme clarified. Filtered through Seitz K3 filter	Clear	—	—	0.029	0.030	0.059	0.019	0.007	1.494
Pressed from Winesap Apples									
Samples filtered through Whatman No. 2 before analysis									
Untreated raw juice	Turbid	—	—	—	—	—	0.085	0.043	1.951
Flash-treated to 89°C. and cooled	Turbid	14.32	0.41	—	—	—	0.082	0.034	2.071

[a] As malic acid. [b] As tannin. [c] Centrifuged by means of laboratory tubular centrifuge operated at a flow rate of 150 ml. per minute.

principal effect on the juice is a reduction of viscosity, through decomposition of pectic substances. Early preparations of these enzymes were of rather low potency and required several days to effect clarification. Reports of changes in composition of juices clarified under such conditions indicated loss of sugar through fermentation. Table 38 gives data on the effect of treatment of several juices with a pectin-decomposing enzyme preparation commercially available in 1939. This preparation was sufficiently potent to produce complete clarification within 12 hours, and juice prepared with its use was found to be slightly higher in sugars because of the presence, to the extent of 81%, of a reducing sugar in the preparation itself. A slight inversion of sucrose resulted from the use of this preparation, and a very slight increase in titratable acidity resulted, the latter presumably from the liberation of free galacturonic acid from the pectin by the enzymes.

The loss of varying amounts of astringent substances, including tannin, has been reported consistently for juice treated with pectin-decomposing enzyme preparations. This loss cannot be explained on the basis of enzyme action and probably is the result of coprecipitation with other suspended material. It will be noted that tannin was found to compose a significant portion of the suspended material that was removed by centrifuging (see Table 37). Losses in alcohol-insoluble fractions accompanied by loss in viscosity are to be expected from the nature of the treatment.

The gelatin–tannin treatment has been found to have a variable effect on astringency and tannin content of apple juice, which is to be expected with this treatment. Losses in viscosity and alcohol-insoluble fractions are also variable but in general have been found to be slightly less than those occurring with the enzyme process. Gelatin-tannin clarification frequently yields a juice of appreciably lighter color than is obtained by enzyme treatment. Table 39 gives a comparison of several juices after treatment with enzymes, gelatin-tannin, and centrifuging after heating. These data show that losses in colloidal substances and viscosity occur even in centrifuged juice that remains cloudy. Although heat treatment has on numerous occasions been referred to as a clarification treatment, data presented in Table 39 indicate that the viscosity of the juice may be increased by heat treatment even though the alcohol-insoluble fractions remain constant. Thus heat probably causes important changes in the pectin materials of the juice in addi-

tion to the probable coagulation of protein material as suggested by many workers.

2. FILTRATION

To effect complete removal of suspended material from clarified apple juice it is necessary to filter or centrifuge the juice. The type of filter medium and equipment used depends somewhat on the method used to accomplish clarification. When clarification is complete, passage of the juice through even a porous filter medium composed of diatomaceous earth is sufficient to produce a brilliantly clear product. When clarification is less complete the juice will remain cloudy unless very retentive filters are used, and the capacity of the filter may be reduced by clogging. Only the most retentive filters are capable of yielding a clear product from unclarified juice. To obtain practical filtration speeds in actual practice, unclarified juice is passed through successively more retentive filters until it can be passed through one sufficiently retentive to yield a clear product. High-speed centrifuging may be used preliminary to filtration to reduce the load on the filters. When unclarified filtered juice is to be preserved by heat it is necessary to subject it to a heat-treatment before filtration to avoid reclouding during pasteurization.

Filters. Filters consist essentially of a support for the filtering medium and means for introducing the juice to this filtering surface and removing it after it has passed through. Types of filters vary widely depending on the particular filtration problem at hand. For small operations simple, homemade, gravity filters may be used which employ a muslin tube to support the filter medium.[612] For large-scale operations plate and frame or alluvial filters, supplied with a mechanical pump, are commonly used. Metals employed in the construction of filters must be corrosion resistant. Selection of the particular type of filter to be used frequently depends on the ease of assembling and operation. The capacity depends on the area of filtering surface presented to the juice and on the volume of juice held within the filter. Centrifuges may be employed in place of the filter but at practical speeds they are incapable of producing a clear juice unless a preliminary clarification treatment has been used.

Filter Mediums. The material through which the juice is passed

[612] R. B. Hickok and R. E. Marshall, *Mich. Agr. Expt. Sta. Quart. Bull., 15,* (3) (1933).

and which serves to retain the suspended material is referred to as a *filter medium*. Filter mediums vary widely as to source and porosity.

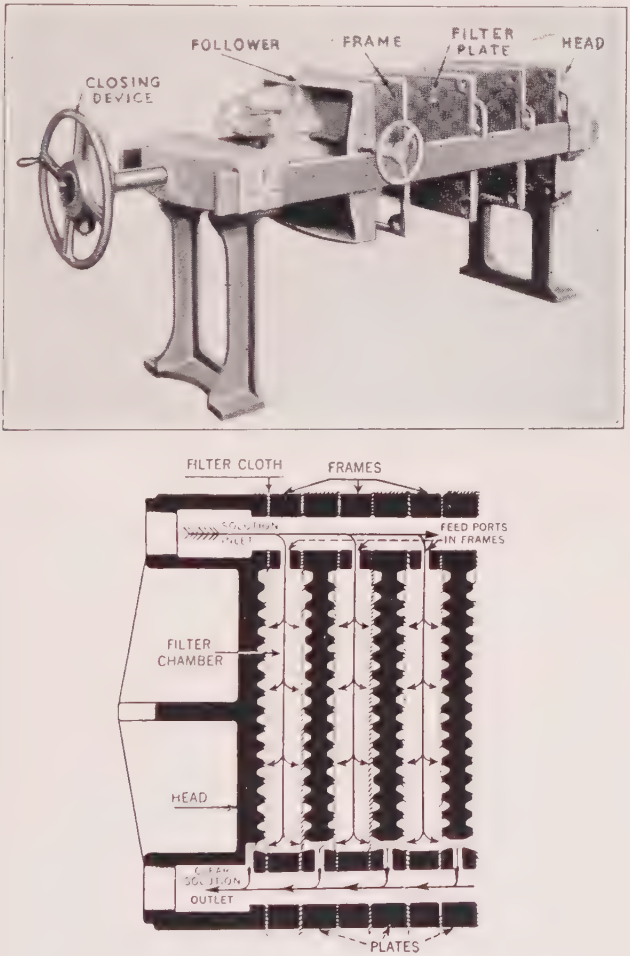


Fig. 78. Essential features of the filter press and assembly.[612a]

In general it may be said that the greater the porosity, the greater will be the speed with which juice will pass through the medium under a

[612a] M. A. Joslyn and G. L. Marsh, *Univ. Calif. Circ. 344*, 29 (1937). A. M. Neubert and J. L. St. John, in M. B. Jacobs, ed., *Food and Food Products*, Vol. II. Interscience, New York, 1944, p. 596.

given pressure. Except for juices that have been completely clarified by a preliminary treatment, the greater the porosity the more turbid will be the juice obtained. The principle of operation of a filter medium is usually considered to be a sieve action, although certain mediums have been found to include the property of adsorbing colloidal materials from solution.[613]

Diatomaceous earth is probably the filter medium most widely used for clarified apple juice. This material consists of siliceous frustulae, or shells, of microscopic, single-celled plants known as *diatoms*. Large beds of these shells were deposited generally throughout the earth in early geological times and some 10,000 distinct forms have been identified. By varying the source of the shells and the process used in preparation, a wide range of porosities may be obtained. When intended for use with juice the product must be thoroughly purified to remove earthy flavors.

For use, the earth is suspended in water and the suspension is then passed through a retaining screen placed on the filter medium support of the filter. The screen may be corrosion-resistant wire cloth, cotton cloth, or paper. Even though the mesh of the screen is sufficiently coarse to permit passage of individual diatom shells the earth quickly collects on the screen to form a porous cake with openings many times as fine as the coarsest mesh. This porous cake is held in position by the flow of water. After thorough washing with water juice is passed through the cake. It is essential that the flow of liquid not be interrupted during the preparation or filtration process so the cake, which cannot support itself, is not disturbed. The clarity of the filtered juice depends on the clarification method used and on the porosity grade of the diatomaceous earth.

Other filtering mediums used are asbestos fiber and paper pulp. They may be used in a manner similar to that described for diatomaceous earth or the material may be formed into sheets or pads and dried. Prepared sheets may be stored and inserted into the filter when needed. Tubes of porous porcelain have also been used as filtering mediums. Care is exercised in the selection of filter mediums that they be inert to the action of apple juice and that they do not impart a taste to the juice.

[613] A. M. Neubert, *Food Research, 8,* 477 (1943).

Filter Aids. Filter aids are generally used in filtration processes to increase the speed of flow and capacity of the filter.[614] Diatomaceous earth is commonly used as a filter aid in the filtration of apple juice, thus often being used both as a filter medium and a filter aid. The required amount of earth is mixed with the juice as it passes to the filter. As the juice passes through the filter medium suspended solids are trapped on its surface. The suspended mucilaginous and hydrophilic solids naturally present in apple juice tend to form a layer impervious to the passage of juice. By simultaneously depositing diatomaceous earth with this mucilaginous material the filter medium may be kept porous during continuous operation until the filter becomes filled with the filter cake.

Effect of Filtration on Juice Quality. A study on the effect of filtration on the appearance, viscosity, and alcohol-insoluble fractions of apple juice,[613] has shown that filtration reduces the viscosity and alcohol-insoluble fractions of the juice. The extent of these effects depends on the type of filter medium used and on the degree of clogging of the filter, but need not be related to the porosity of the filter as determined by the speed of flow or by the clarity of the filtered juice. Centrifugal force was found to be as effective in reducing the viscosity and alcohol-insoluble fraction content of juice as was filtration through the most retentive filter mediums before they became clogged, although centrifuged juice remained turbid. Figure 79 shows the effect of filtration through various Seitz filter sheets on the viscosity and alcohol-insoluble fractions of successive volumes of flash-heated and cooled apple juice passed through at a uniform pressure. Several of these filter sheets show a pronounced ability to adsorb colloidal substances from juice during the initial filtration period. Juices from which a major portion of colloidal material has been removed by clarification do not suffer marked additional losses during filtration.

It therefore appears that loss of viscosity, or body, and of colloidal fractions responsible for this viscosity, must accompany any process to which apple juice is subjected to remove suspended solids. The loss in viscosity may be restored, if considered desirable, by replacing the pectin lost during clarification. Losses in other constituents that contribute to the flavor and properties of apple juice depend on the type of clarification treatment used, but in general these changes are

[614] G. M. Hickey, *Ind. Eng. Chem., 13,* 990 (1921). R. N. Cogger and H. M. Merker, *Ind. Eng. Chem., 33,* 1233 (1941).

Fig. 79. Curves showing the effect of filtration through various Seitz filter sheets on the viscosity, alcohol precipitate, and pectic acid of successive volumes of effluent.[813] Horizontal lines between points indicate respective values for the same juice subjected to a centrifugal force 9500 times gravity (open circles, viscosity; closed circles, alcohol precipitate; half-closed circles, pectic acid).

not as great as natural variations found in these constituents when comparing a variety of juices. Filtration also has the beneficial effect of removing microorganisms from juice (page 360).

3. DEAERATION

The value of deaeration, a treatment found necessary in the retention of flavor and vitamin in citrus and certain other juices has been controversial among workers studying apple juice,[615-624] some claiming an improvement in flavor and aroma retention during storage, whereas others find no benefit. Some value may be realized in a reduced tendency to corrode tin plate but losses in volatile flavor constituents are encountered. Although practiced to some extent, the majority of commercial apple juice processors do not deaerate their product. Deaeration is accomplished by drawing the juice into a chamber evacuated to at least 28 inches of mercury and so constructed that the juice is sprayed into it as a fine mist or as a thin film flowing over suitable baffles.

Extraction by conventional presses results in a thorough aeration of apple juice and enzymically catalyzed flavor and color changes that occur during pressing cannot be reversed by subsequent deaeration. Vitamin C, normally low in apple juice, is almost completely converted to the dehydro form during preparation, whether deaeration is practiced or not. In the case of pulpy apple juice (page 329) prepared in comminution machines which make possible the extraction of the juice in an inert atmosphere whereby browning is avoided, it is essential that deaeration follow extraction if the natural, light color of the apple is to be retained. The value of deaeration can be com-

[615] W. V. Cruess, H. Aref, and J. H. Irish, *Fruit Products J., 12,* 358 (1933).
[616] D. A. Tucker, G. L. Marsh, and W. V. Cruess, *ibid., 15,* 7 (1935).
[617] M. A. Joslyn, *ibid., 16,* 234 (1937).
[618] R. W. Arengo-Jones, *ibid., 17,* 105 (1937).
[619] R. F. Celmer and W. V. Cruess, *ibid., 16,* 356, 379 (1937).
[620] V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta. Long Ashton, Bristol, 1936,* 195 (1937).
[621] C. S. Pederson and D. K. Tressler, *Ind. Eng. Chem., 30,* 954 (1938).
[622] H. H. Mottern, A. M. Neubert, and C. W. Eddy, *Fruit Products J., 20,* 36, 55, 57 (1940). H. L. Sipple, G. H. McDonell, and R. H. Lueck, *ibid., 19,* 167 (1940).
[623] R. W. Arengo-Jones, *Fruit Products J., 20,* 7, 23 (1940). J. Tavernier and P. Jacquin, *Bull. Assoc. Chim., 63,* 111 (1946); *Chem. Abstracts, 41,* 1948.
[624] R. E. Marshall, *Ind. Eng. Chem., 33,* 285 (1941); *Mich. Agr. Expt. Sta. Circ.,* 206, 1947.

pletely lost unless special devices are used in filling and sealing the containers, since the amount of air entrapped in the head space of the container during the usual operation is greater than that which can be removed by deaeration.[625] Reaeration of juice during the filling and sealing operations may account for the lack of benefit from deaeration observed by some workers.

4. VITAMIN FORTIFICATION

Many consumers of fruit juice associate their value in the diet with their content of vitamin C and frequently consider the different

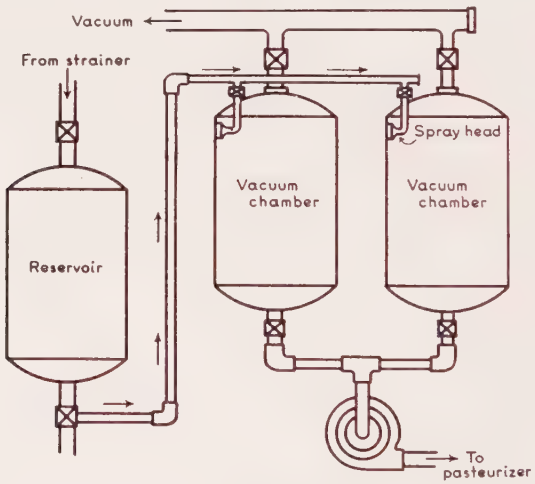


Fig. 80. Diagrammatic representation of a deaerating unit.[624a]

juices as interchangeable in this respect. For this reason considerable attention has been given to the problem of fortifying processed juices that are normally low in this vitamin. In 1943 the Canadian government required that commercially canned apple juice meet a minimum standard of 35 milligrams of ascorbic acid per 100 milliliters of juice, and enriched apple juice was used in U. S. Army rations during World War II. Increased vitamin fortification of commercially packed apple juice may be expected in the future.

[624a] A. M. Neubert and J. L. St. John, in M. B. Jacobs, ed., *Food and Food Products*, Vol. II. Interscience, New York, 1944, p. 599.
[625] R. H. Lueck and R. W. Pilcher, *Ind. Eng. Chem., 33,* 292 (1941).

Studies on fortification of apple juice with L-ascorbic acid[626] [630] have demonstrated that apple juice can be made comparable to citrus juices in vitamin C content by adding about 50 milligrams of L-ascorbic acid per 100 milliliters of juice. When properly added, ascorbic acid is well retained by the juice during processing and storage at room temperature. Improvements in flavor and color retention during storage have also been observed as a result of fortification.

L-Ascorbic acid may be added to apple juice by dissolving the crystals in a small volume of juice and adding this solution to a measured volume of juice in a holding tank. After a short mixing the juice is pasteurized, sealed, and cooled as rapidly as possible to avoid vitamin destruction. Deaeration is recommended before fortification to reduce the loss of ascorbic acid from oxidation. The containers are filled with a minimum of headspace, as oxygen sealed in the container destroys the vitamin during storage. The vitamin may also be added in the form of tablets, the tablet being introduced into each container just before filling or sealing The addition of ascorbic acid to the freshly milled apples at the rate of 6 grams per bushel of apples (40—45 pounds) was found to result in an ascorbic acid level of about 20 to 25 milligrams per 100 grams of pasteurized juice.[630a] Addition of ascorbic acid during milling had the added advantage of preventing initial darkening of the juice during pressing. A simple plant procedure for estimating the vitamin C in enriched apple juice by direct titration with standard iodine solution has been proposed.[631]

[626] C. C. Strachan, *Can. Dept. Agr. Tech. Bull.*, 40, 1942.
[627] F. B. Johnston, *Fruit Products J., 22,* 195 (1943).
[629] C. S. Pederson and H. G. Beattie, *Food in Canada, 4,* (4), 11 (1944); *Chem. Abstracts, 39,* 1701.
[629] W. B. Esselen Jr., J. J. Powers, and C. R. Fellers, *Fruit Products J., 26,* 11, 29 (1946).
[630] F. E. Huelin and R. S. Mitchell, *Australian Food Manuf. 13* (8), 4 (1944); *Chem. Abstracts, 38,* 2759.
[630a] K. C. Holgate, J. C. Moyer, and C. S. Pederson, *Fruit Products J., 28,* 100, 112 (1948).
[631] J. C. Bauernfeind and F. W. Jahus, *Food Packer, 27* (9), 64 (1946).

5. CARBONATION

Studies have been reported on the preparation of carbonated apple juice.[632-637] Clarified and filtered juice may be carbonated in equipment used for the carbonation of water by the carbonated beverage industry, provided corrosion-resistant metals have been used in those parts which come in contact with the juice. Apple juice concentrate may also be used for the preparation of the carbonated juice by placing the required amount of concentrate in the bottle and filling with carbonated water. Use of about 2.5 volumes of carbon dioxide for each volume of apple juice has been suggested as suitable for this beverage. A higher carbonation is desired for very sweet juice than for highly astringent juice. The apple juice may be filtered sterile (page 360) before carbonation and handled aseptically until sealed in the bottle or the product may be pasteurized after bottling. At a given pressure cloudy juices have been observed to take up more carbon dioxide than filtered juices.[638]

Although carbonated apple juice has been described as comparable in flavor appeal to other carbonated beverages, commercial production of this product is limited and is of negligible importance in comparison with the production of other carbonated beverages. Improved quality in the carbonated juice results from the use of astringent, cider varieties of apples.

6. BLENDS WITH OTHER FRUIT JUICES

A number of studies have been made on the use of apple juice in blends with juice from other fruits. The fresh, but mild, fruit flavor of apple juice serves as an ideal base and is relatively inexpensive to produce in comparison with juices prepared from such fruits as the dewberries for example. Highly flavored juices, when blended with apple juice, retain much of their characteristic flavor, even

[632] D. C. Carpenter, *Natl. Bottlers' Gaz., 52* (620), 50 (1933); *Fruit Products J., 13,* 37, 59 (1933).
[633] J. H. Irish, *Fruit Products J., 12,* 196 (1933).
[634] H. D. Brown and C. W. Foulk, *Ohio Agr. Sta. Bimonthly Bull., 24,* 1939, pp. 5-6.
[635] R. F. Celmer and W. V. Cruess, *Fruit Products J., 16,* 229, 251 (1937).
[636] V. L. S. Charley, *ibid., 18,* 207, 217, 219, 241, 248 (1939).
[637] R. W. Arengo-Jones, *ibid., 18,* 297 (1939).
[638] J. Jenny, *Schweiz. Z. Obst.-u. Weinbau, 50,* 353 (1941); *Chem. Abstracts, 38,* 1808.

though apple juice predominates in quantity present, and do not assume a watery character obtained by dilution with equivalent amounts of sugar sirup. Blends of apple with other juices that have been proposed are presented in Table 40. In general these blends are most suitably prepared by holding the berries in a frozen state until the apple season and then thawing them in apple juice and pressing the mixture. Heating the mixture has been found desirable in some fruits to in-

TABLE 40. Some Successful Blends of Apple Juice with Other Fruit Juices

1.	Apple juice, 75.8%; raspberry juice, 20.3%; sugar, 3.9%[a]
2.	Apple juice, 1–2 parts; prune juice, 1 part[b]
3	Apple juice, 45 parts; cherry juice, 55 parts[c]
4.	Apple juice, 37 parts; fresh Italian prune juice, 63 parts[c]
5.	Apple juice and Japanese quince juice[d]
6.	Apple juice, 78%; elderberry juice, 20%; sugar, 2%[e]
7	Apple juice, 62%; strawberry juice, 38%[e]
8	Apple juice, 85%; cranberry juice, 15%[f]

[a] C. S. Pederson, H. G. Beattie, and E. A. Beavens, *Fruit Products J.*, *20*, 227, 247 (1941).
[b] W. V. Cruess, *ibid.*, *20*, 164, 187 (1941).
[c] H. G. Beattie and C. S. Pederson, *ibid.*, *21*, 227, 240, 251, 253 (1942).
[d] A. S. Levine, *ibid.*, *21*, 177 (1942).
[e] C. S. Pederson and H. G. Beattie, *ibid.*, *22*, 260, 281, 287 (1943).
[f] K. M. Hayes, W. B. Esselen, Jr., and C. R. Fellers, *ibid.*, *27*, 308, 329 (1948).

crease color extraction. In preparing a blend of apple and cranberry juices it was found necessary to give the apple juice a preliminary flash-pasteurization treatment in order to inactivate enzymes which would otherwise destroy the red color of the cranberry juice when the two are mixed together prior to final processing.[638a]

E. Preservation

Apple juice not intended for immediate consumption must be subjected to some preservation process to prevent spoilage. The juice does, however, possess bactericidal action against certain organisms. In a study of longevity of pathogenic bacteria in apple juice[639]

[638a] K. M. Hayes, W. B. Esselen, Jr., and C. R. Fellers, *Fruit Products J.*, *27*, 308, 329 (1948).
[639] J. Forgacs and F. W. Tanner, *Fruit Products J.*, *22*, 295, 304 (1943).

it was found that clarified unpasteurized juice was more bactericidal than unprocessed or clarified pasteurized juice. *Escherichia coli* and *Eberthella typhosa* decreased more rapidly at 3°F. than at 41°F. and least at room temperature. *Escherichia coli* was more resistant than *Salmonella aertycke* in the same juice. Juices to which tannic and malic acids were added were considerably more bactericidal than untreated juice. Similar bactericidal properties of apple juice have been reported by European workers.[640]

1. PRESERVATION BY HEAT

The most important commercial method of preservation is pasteurization. This method depends on the destruction by heat of those microorganisms capable of growth in juice packed in hermetically sealed containers. To retain the fresh flavor and aroma of apple juice, heating may be limited to that necessary to destroy yeast. Bacteria surviving such treatment are not capable of growth in a medium as acid as apple juice, and mold growth is prevented by the elimination of oxygen from the container. The temperature should be sufficiently high to inactivate enzymes capable of causing deterioration in the quality of the juice during storage.

The thermal destruction of microorganisms is a function of both time and temperature. It has been shown[641] that certain fruit juices can be preserved successfully by heating to a temperature of 135°F. for several hours, to 150°F. for 30 minutes, or to 170°F. for 1 minute. The minimum safe time and temperature required to preserve a given juice varies with its acidity, heat conductivity, and initial contamination with microorganisms. A microbiological analysis of apple juice processing has shown flash pasteurization at 175°F. for 10 seconds sufficient to preserve this product, while a temperature of 168°F. for the same period resulted in spoilage.[642] In another study[643] holding pasteurization at 155°F. or higher for from 15 to 20 minutes, or flash pasteurization at 160°F. or higher were found adequate for tart juices, whereas higher temperatures were required for juices low

[640] U. Scholz, *Obst- u. Gemüse-Verwertungs-Ind., 30,* 266 (1943); *Chem. Abstracts, 39,* 3086.
[641] C. S. Pederson and E. A. Beavens, *Food Inds., 12* (4), 61 (1940).
[642] J. Forgacs, *Food Research, 7,* 442 (1942).
[642a] E. M. Chace, H. W. von Loesecke, and J. L. Heid, *U. S. D. A. Circ., 577,* 11 (1940). A. M. Neubert and J. L. St. John, in M. B. Jacobs, *op. cit.,* p. 601.
[643] C. S. Pederson and D. K. Tressler, *Ind. Eng. Chem., 30,* 954 (1938).

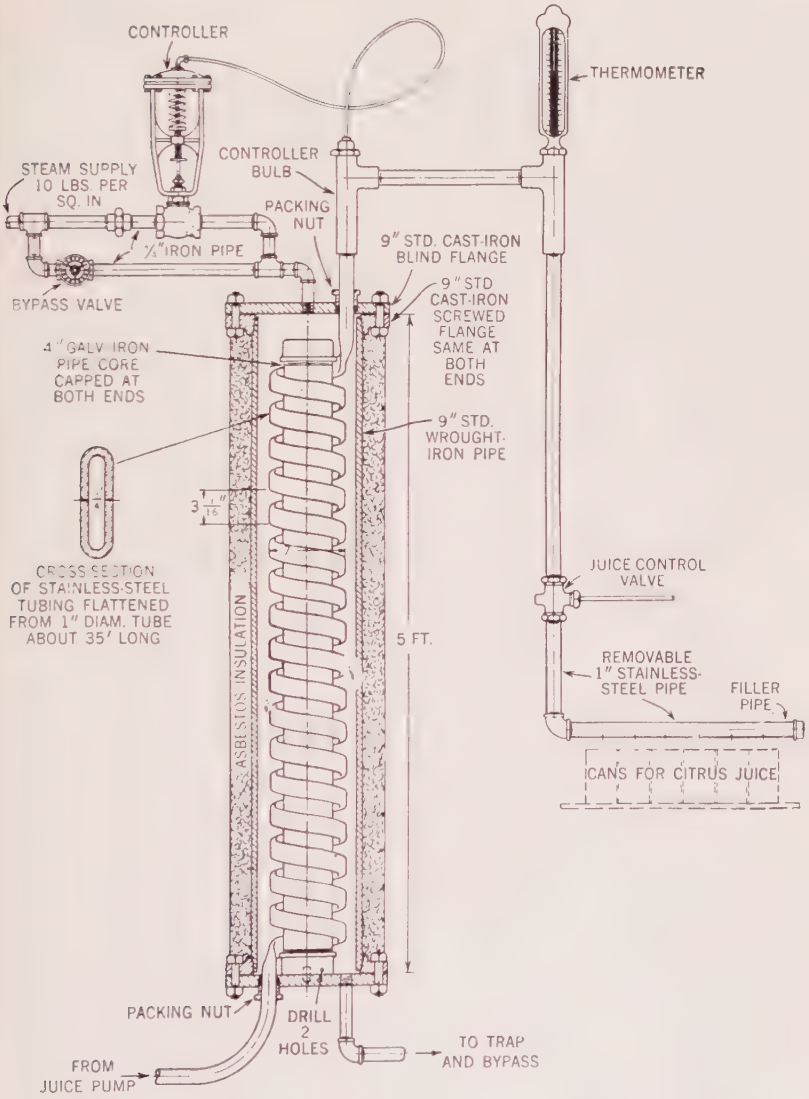


Fig. 81. Commercial flash pasteurizer.[1124]

in acid. Although cooked flavors may develop in cloudy juices flash-pasteurized at 180°F., workers are generally agreed that such flavors do not develop at temperatures of 190°F. or even higher in clarified juice when the juice is flash-heated and rapidly cooled.

Holding Pasteurization. Two general types of pasteurization have been developed for preserving fruit juices. Either method, when properly applied, is successful in retaining the natural, fresh flavor of the juice. The older method, holding pasteurization, depends on the use of a relatively low temperature maintained over an extended period. The containers may be filled with juice at or below the temperature to be used during pasteurization. After the containers have been sealed they are brought to the required temperature by means of a water bath or spray and held at that temperature until pasteurization is complete, after which they are water cooled. Temperatures of 155°F., held for 15 to 20 minutes, have proven suitable for apple juice. This method requires rather elaborate equipment for holding large numbers of containers at the desired temperature.

Flash Pasteurization. More recently flash pasteurizers have been introduced for the preservation of fruit juices.[644–649] The process depends on the use of a temperature sufficiently high to accomplish preservation in a relatively short time. The juice is heated to the required temperature in a few seconds as it passes through tubes or between the plates of a heat exchanger. Several types of flash pasteurizers have been developed for the purpose of preserving fruit juices and the equipment includes controls capable of maintaining the desired temperature within a close range. The hot juice is usually filled directly into the containers, which in the case of glass, are given a preliminary heating to avoid thermal shock. The containers are sealed and then rapidly cooled in water. Unless some method of heating is employed to sterilize the lids it is necessary that the sealed container be inverted before cooling so that the hot juice may ac-

[644] H. H. Mottern and H. W. von Loesecke, *Fruit Products J., 12,* 325 (1933).
[645] J. L. Heid and W. C. Scott, *ibid., 16,* 136 (1937).
[646] R. E. Marshall and J. C. Kremer, *Mich. Agr. Expt. Sta. Quart. Bull., 20,* (7) (1937).
[647] C. S. Pederson and D. K. Tressler, *Ind. Eng. Chem., 30,* 954 (1938).
[648] R. W. Arengo-Jones, *Fruit Products J., 20,* 7, 23 (1940).
[649] R. E. Marshall, *Ind. Eng. Chem., 33,* 285 (1941).

complish sterilization. Temperatures commonly employed in flash-pasteurizing apple juice vary from 175° to 200°F. and the entire period during which the juice remains hot is generally limited to from 1 to 3 minutes. Flash pasteurization may also be accomplished by sealing juice in cans while cold and rapidly spinning the cans in a spray of hot water or steam, followed by a cold-water spray after pasteurization temperatures have been attained.[650] When the latter method is used the cans are sealed under vacuum, created either mechanically or by means of a steam jet, to expel air from the head-spaces.

Packaging. Filling and sealing the container are integral parts of the heat-preservation process since the container must be sterilized and sealed to insure preservation of the juice. Many types of fillers have been developed, the simplest of which consists in passing the containers under a spout or perforated pipe from which the juice flows. When the container is filled and sealed at the pasteurization temperature a partial vacuum is created as a result of the contraction of the juice during cooling. When containers are filled and sealed cold or at a temperature below that attained in pasteurization, sufficient head space must be left to allow for the expansion of the juice during heating. A satisfactory method of insuring a vacuum in cold-filled juice is to fill the head space with live steam during the sealing operation. Condensation of the steam after sealing results in a partial vacuum. When the process of preparing the juice has been carried out in such a way that oxidation has been prevented it is desirable to use special filling and sealing equipment so that oxygen, which would tend to nullify previous precautions regarding oxidation, will not be sealed in the container. Rapid cooling of the juice after pasteurization is essential to avoid the development of a cooked flavor.

2. PRESERVATION BY FREEZING

Probably the most satisfactory method for preserving the fresh flavor of apple juice is by freezing. Juice preserved in this manner need not receive any heat treatment, and flavor changes which occur in canned juice during storage at higher temperatures are retarded. Freezing causes an effective reduction in the number of microorgan-

[650] R. Berkness, *Fruit Products J., 19,* 122, 185 (1940).

isms present but does not result in a sterile juice.[651, 654] It is therefore necessary to handle the juice after thawing in the same way as fresh juice. A study of the effect of storage temperature on the quality of frozen apple juice has shown that storage at —6°F. results in better flavor and vitamin C retention over prolonged periods than storage at +15°F.[655] Better flavor and vitamin C retention during freezing storage were also realized in pasteurized juice than in raw juice.

Commercial use of freezing preservation is still quite limited because of problems connected with distribution of the product in the frozen condition and because of the cost of the process. To retain its fresh flavor apple juice is frozen as soon after preparation as possible. The juice is usually frozen in tin or fiber containers that have been filled to less than nine tenths of their capacity to allow for expansion during freezing. Cellophane bags commonly used in packaging solid frozen foods have been found inconvenient.[656] Apple juice may be frozen in large containers for later thawing and distribution as fresh juice or cider. Both cloudy and clarified juice are frozen.

3. PRESERVATION WITH CHEMICALS

Chemicals used in the commercial preservation of apple juice are confined principally to sodium benzoate, sulfurous acid including its salts, and CO_2. Among other chemicals proposed as useful in preservation of apple juice are monochloroacetic acid,[657] fluorides, alkali chromates, boric acid, salicylic acid, abrastol, formaldehyde, and derivatives of β-naphthol.[658] Recently the use of propylene oxide in amounts from 0.5 to 1.0% by volume has been proposed for the sterilization of apple juice.[659] On standing the propylene oxide hydrolyzes to propylene glycol. Although some of these compounds are effective in preventing spoilage in apple juice when used in adequate amounts, their use is confined to the preservation of

[651] J. A. Berry and H. C. Diehl, *Proc. Am. Soc. Hort. Sci., 32,* 157 (1934).
[652] V. H. McFarlane, *Food Research, 5,* 59 (1940).
[653] J. Forgacs, *ibid., 7,* 442 (1942).
[654] J. Forgacs, W. A. Ruth, and F. W. Tanner, *ibid., 10,* 148 (1945).
[655] F. A. Lee, H. G. Beattie, W. B. Robinson, and C. S. Pederson, *Fruit Products J., 26,* 324 (1947).
[656] W. V. Cruess and A. J. Glazewski, *ibid., 25,* 5, 27 (1945).
[657] F. W. Fabian and E. F. Bloom, *ibid., 21,* 292 (1942).
[658] Anon., *Verhandl. kais. Gesundheitsamt, 32,* 1292 (1908); *Chem. Abstracts, 3,* 554. R. D. Scott and E. C. Will, *Ind. Eng. Chem., 13,* 1141 (1921).
[659] E. C. Haines, U. S. Pat. No. 2,354,014, July 18, 1944; *Chem. Abstracts, 38,* 6004.

samples for chemical analysis because of their well-known, or possible toxic effect to humans. The Federal Government and many states require a declaration of the presence of added chemical preservatives on the container in which such products are marketed.

Sodium Benzoate. Sodium benzoate is used extensively to increase the shelf life of unpasteurized apple juice. It is effective in preventing spoilage when present in concentrations of from 0.05 to 0.3%, the quality necessary varying with the acidity of the juice.[660] In a study of the relative value of sodium benzoate preservation as compared with cold storage it was found that sodium benzoate treated apple juice became unpalatable after 30 days storage at 68°F., whereas untreated juice became unpalatable after 15 days storage at the same temperature. Juice stored at 41°F. in glass containers remained practically unchanged for 60 days without the addition of sodium benzoate.[662] Apple juice which is to be marketed fresh is usually treated with 0.1% sodium benzoate which has been dissolved in a small amount of water and added to the juice as soon after pressing as possible. Sodium benzoate of high purity is required to minimize flavor change. Its presence can usually be detected in the flavor of the juice.

Sulfurous Acid. Sulfurous acid is not widely used in preserving apple juice intended for beverage purposes but is more commonly used in preserving juice for bulk export, fermentation, or other manufacturing purposes. Its presence in sufficient quantity to prevent spoilage, from 0.02 to 0.1%, results in bleaching of the juice and it can be detected in the flavor of the product. The progressive disappearance of free sulfurous acid, particularly in juice prepared from apples containing decay or mold, makes it necessary that the products be inspected periodically to assure the presence of sufficient chemical for preservation.[663] Sulfurous acid may be added in the form of salts or as sulfur dioxide gas.

Carbon Dioxide. Fresh apple juice may be stored for extended periods without microbial spoilage if held under carbon dioxide at

[660] C. R. Fellers, *Fruit Products J., 9,* 113 (1929). H. C. Gore, *U. S. D. A. Bull.,* 118, 1908. W. V. Gruess, P. H. Richert, and J. H. Irish, *Hilgardia, 6,* 195 (1931).

[661] W. V. Cruess, *Food Manuf., 7,* 176, 181 (1932); *Chem. Abstracts, 26,* 4384.

[662] C. F. Poe and J. T. Field, *Fruit Products J., 27,* 112, 123 (1947).

[663] G. Warcollier and Le Moal, *Compt. rend., 174,* 634 (1922); *Chem. Abstracts, 16,* 1818. G. Warcollier and Le Moal, *Chimie & industrie, Special No. 624,* 30 (1925); *Chem. Abstract, 20,* 475.

pressures of about 120 pounds per square inch.[664] This process, developed by Professor Böhi in 1912 in Switzerland, is commonly used in conjunction with sterile filtration (page 360). The process has been successfully operated on an experimental basis in the United States[665,666] but has not received wide commercial use up to present time. Tanks, equipped with suitable, inert linings,

Fig. 82. Glass-lined pressure tanks for bulk storage of unfermented apple juice by the Böhi process. This process is used commercially in Europe (courtesy The Pfaudler Co.).[666]

and capable of withstanding high pressure are filled with carbon dioxide (dry ice may be used) under 120 pounds pressure and the juice, which may or may not be previously clarified, is pumped into the tank in such a way that it becomes thoroughly impregnated with the gas (Fig. 82). As long as the temperature is maintained below 60° F. and the pressure of the carbon dioxide is 120 pounds or more, complete inactivation of microorganisms is achieved. Lower

[664] V. L. S. Charley and T. H. J. Harrison, *Imp. Bur. Hort. Plantation Crops, East Malling, Kent, Tech. Commun., No. 11* (1939).
[665] H. D. Brown and C. W. Foulk, *Ohio Agr. Expt. Sta. Bimonthly Bull., 24,* 5 (1939).
[666] E. M. Hallowell, *Fruit Products J., 20,* 368, 387 (1941).

pressures may be adequate at lower storage temperatures. It has been found impossible, however, to sterilize juice by subjecting it to carbon dioxide pressures up to 125 pounds for periods up to 30 hours.[668] Böhi stored juice is usually processed for distribution by sterile filtration so that the product may be handled throughout without the use of heat. The carbon dioxide is removed from the juice and may be recovered for reuse by compression into suitable cylinders, while the juice is processed as outlined under sterile filtration (page 360). Proponents for this process[669] claim an improvement in the flavor of the juice as a result of a mellowing process during storage similar in nature to that occurring during the aging of wines. Some experiments have also been made on the use of mold mycelium preparations to hasten these desirable flavor changes.

Oligodynamic Processes. The use of minute quantities of colloidally dispersed silver, introduced into the juice by electrolysis, has been proposed as a means of preserving apple juice.[670] At least 5000 γ of silver per liter of juice is required to maintain sterility for extended periods. With the use of 7500 γ or more of silver off-flavors become apparent. The *Katadyn process*[671] sterilizes at ordinary temperatures whereas the *Matska process* employs an elevated temperature.[672] By incorporating less than 1 part of silver per million of juice by elecrolysis it has been reported possible to achieve sterilization of apple juice at pasteurization temperatures from 15° to 20°F. below that required without electrolysis. These processes have not been found practical in the United States for the commercial preservation of apple juice, although the Matska process is reported to be used in conjunction with pasteurization in some European countries. Electrical treatment, using aluminum electrodes, has also been proposed for sterilizing apple juice.[673]

[668] H. D. Brown, C. Fitzgerald, and F. Neuman, *Proc. Am. Soc. Hort. Sci., 36,* 371 (1939).

[669] Z. I. Kertesz, *Food Inds., 18,* 496, 632 (1946).

[670] A. Mehlitz, *Obst- u. Gemüse-Verwertungs-Ind., 23,* 49, 67 (1936); *Chem. Abstracts, 31,* 7137.

[671] A. Katadyn, Brit. Pat. No. 492,745, Sept. 26, 1938; *Chem. Abstracts, 33,* 1844.

[672] V. L. S. Charley and T. H. J. Harrison, *Imp. Bur. Hort. Plantation Crops. East Malling, Kent, Tech. Commun.,* No. 11 (1939).

[673] V. M. Wright, U. S. Pat. No. 987,845, March 28, 1911; *Chem. Abstracts, 5,* 1876.

4. STERILIZATION BY FILTRATION

The possibility of sterilizing apple juice through removal of spoilage organisms by filtration has long appealed to processors because juice preserved in this manner has the psychological appeal that it has never been heated or changed in any way and therefore most closely resembles the freshly pressed juice. Cold-sterilized juice has been described[674] as being fresher and cleaner flavored than the pasteurized product though less intensely flavored. It was considered more desirable for juices prepared from cider varieties than from culinary apples. The process consists of passing the juice through suitably prepared filters capable of removing microorganisms, and thereafter handling the effluent under aseptic conditions. This method obviously can be used only for juices to be marketed in a perfectly clear condition. The process was developed and is used extensively in Europe but has not been adapted to conditions in the United States, where occasional difficulty with spoilage and the extreme care necessary has delayed the application of the process to large-scale production methods.

Theoretical Considerations. The principle by which special filter mediums accomplish sterilization of juice passed through them is not well understood. Almost all filtration mediums and centrifuging cause a marked reduction in the microorganisms present in juice. Diatomaceous earth has been found particularly effective in this respect,[675] removing up to 99.9% of the microorganisms from juice during passage. Nevertheless, only special filter mediums are capable of completely removing microorganisms to produce a sterile juice. Determinations of the pore size of these special mediums indicate that the action of such filters is definitely not that of a sieve,[676] since the pore size may be many times the longest dimension of the organisms that are removed. Under proper operating pressures, organisms are completely removed in passing through the filter, whether the diameter of the capillary they pass through is five or thirty times as large as their greatest dimension. Experiments have shown that most of the organisms trapped by asbestos paper pulp filter mediums are distributed on the intake side of the filter and relatively few organisms are carried any appreciable distance into the capillaries. Studies on the

[674] V. L. S. Charley, *Fruit Products J., 18,* 207, 217, 219, 241, 248 (1939).
[675] J. Forgacs, *Food Research, 7,* 442 (1942).
[676] D. C. Carpenter, C. S. Pederson, and W. F. Walsh, *Ind. Eng. Chem., 24,* 1218 (1932).

filtration of juice[677] have shown that sterilizing filters of the asbestos paper pulp type are capable of adsorbing colloidal materials by other than sieve action.

Sterilization. The use of the sterilizing filter must be accompanied by certain precautions to insure a sterile effluent. After the filter has been assembled with the sterilizing sheets in place the entire assembly is sterilized by passing live steam through it. Cold water is then pumped through the filter to cool it and wash from the filter sheets any off-flavor that may otherwise pass into the juice. Juice that has been previously clarified and filtered is then pumped through the sterilizing filter, care being taken that the pressure of the juice delivered to the filter does not rise above the limit at which a sterile juice results. Pressures recommended vary from 10 to 22.5 pounds per square inch.

Bottling. The problems of obtaining a sterile juice are relatively simple compared with those encountered in maintaining the juice in a sterile condition while filling and sealing it into sterile containers. In order to maintain aseptic conditions the room in which the sterilization and bottling are conducted is usually treated with steam, 2% sulfur dioxide fumes, or a formalin solution. Specially filtered air may also be blown into the bottling room and workers are supplied with sterilized clothing. All operations from the time the juice leaves the outlet of the sterilizing filter to filling and sealing the container must be carried out in such a way that recontamination with microorganisms cannot occur. When the juice is bottled directly, the bottles are first sterilized by heat or by soaking in a solution containing an equivalent of 2% sulfur dioxide. Caps or corks used in closing the bottles are also sterilized by soaking for a sufficient period in sulfurous acid or formalin solutions. Excess sterilizing agents are removed from the equipment and containers by rinsing with sterile water. Sterilization by filtration is usually restricted to juice packed in bottles so that the product may be examined after a short incubation period and those bottles accidentally contaminated with mold removed.

Bulk Storage. It is possible to fill sterile filtered juice into suitably sterilized and protected bulk tanks for storage but this procedure is accompanied by definite risks. It is necessary that the tanks be constructed of material capable of sterilization, and that they be protected during storage from contamination by organisms. Sulfur dioxide

[677] A. M. Neubert, *Food Research, 8,* 477 (1943).

fumes are frequently used to sterilize bulk tanks which are fitted with special attachments to filter and sterilize any air that may gain access to the tank during filling, storage, or emptying.

5. ULTRAVIOLET LIGHT AND X-RAYS

Ultraviolet light has been suggested as a means of sterilizing apple juice without use of heat or chemicals but commercial use of this method has not developed. A study of the killing powers of ultraviolet light showed that 30 to 83% of yeast organisms and 33 to 72% of molds were killed in apple cider through layers varying from 2 to 25 millimeters in thickness. A greater part of the light was absorbed by coloring matter. Greater effectiveness was shown in samples decolorized with charcoal but the method was considered impractical for sterilization purposes.[678]

Preliminary studies on the use of x-rays and cathode rays to destroy microorganisms indicate the possibility of their use in sterilizing apple juice by a continuous process.[679] X-rays produced at approximately 3 megavolts readily destroyed bacteria, yeasts, and molds in massive concentrations in pure cultures and when associated with solids or liquid substrates such as apple juice. The application of 25,000 röntgens destroyed 94 to 99.9% of the non-spore-forming bacteria but 10 to 20 times as many röntgens were occasionally required to achieve complete destruction of residual bacteria. Doses of 500,000 röntgens usually destroyed all non-spore-formers and 99.9% or more of the spore formers. The dose required to destroy bacteria with cathode rays was similar to that necessary with x-rays. However, it was possible to obtain the results more rapidly with cathode rays than with x-rays because the available output in röntgens per minute of cathode rays is much greater than when the same equipment is used for x-rays.

6. CONTAINERS FOR JUICE

Apple juice was originally packed exclusively in bottles. This was due in part to the fact that apple juice is very corrosive on tin plate and the quality of the juice is seriously depreciated during this

[678] C. F. Rudoff, W. Herbst, and E. Schneiders, *Landw. Jahrb., 84,* 843 (1937); *Chem. Abstracts, 32,* 1385.

[679] C. C. Dunn, W. L. Campbell, H. Fram, and A. Hutchins, *J. Applied Phys., 19,* 605 (1948); *Chem. Abstracts, 42,* 8227.

corrosion. Ordinary sanitary enamel cans are likewise unsatisfactory. With the development of specially enameled tin plate, originally intended for wine, considerable quantities of juice were packed in tin. Studies on the keeping quality of apple juice in bottles and tin containers have shown[680,681] that apple juice will keep equally well in either suitably enameled tin or in glass and the use of colored glass is of no advantage. A slight preference was found for canned juices which was considered due to the shorter period of heating to which juice in cans was subjected. Immediately before the war about 90% of the apple juice packed in the United States was in tin. The pack was converted completely into glass during the wartime shortage of tin plate. Opinions differ as to whether or not this pack will revert to cans once tin again becomes plentiful. Some packers maintain that the advantage of display realized in glass containers will more than offset the added cost of shipping in glass. With the improvement in quality of glass containers, and the practical solution of many of the difficulties encountered in handling glass on a production line basis, use of bottles is more probable than during the prewar period.

7. STORAGE

Flavor and Aroma Changes. Preserved apple juice depreciates in quality during storage. The chemical changes involved in this deterioration are not well understood but oxygen and temperature are important factors in determining stability during storage. Results of experimental studies on the effect of light on apple juice quality have been controversial. In one study the red end of the spectrum was observed to darken apple juice and affect the flavor and aroma favorably while the blue end caused a fading in color and diminution of flavor.[682] Another study showed no benefit to apple juice when stored in green or brown bottles, as compared with plain bottles.[681] The value of added ascorbic acid, a chemical which consumes oxygen during decomposition, in preserving flavor during storage has been indicated (page 349). Regardless of the process used in preparing apple juice a distinct deterioration in flavor and aroma occurs during pro-

[680] H. H. Mottern, A. M. Neubert, and C. W. Eddy, *Fruit Products J., 20,* 36, 55, 57 (1940).
[681] C. S. Pederson, H. G. Beattie, and E. A. Beavens, *Proc. Food Conf. Inst. Food Technol., 1940,* 205.
[682] D. C. Carpenter, *Ind. Eng. Chem., 25,* 932 (1933).

longed storage at room temperature. Flavor retention is improved by cold storage[684] and the original flavor can be retained for prolonged periods at 0°F. In a study of changes occurring in fruit juices during storage it was observed that apple juices stored at elevated temperatures (90° to 113°F.) developed a brown color, with an increase in yellow and red, within two weeks and these changes increased with prolonged storage at these temperatures. The addition of ascorbic acid inhibited the color change but the ascorbic acid was partly destroyed during storage. Marked losses also occurred in the viscosity of unclarified apple juice during high-temperature storage. Color and ascorbic acid were well retained in apple juices stored below 70°F.[685] Changes in color were considered the most objective and sensitive means for measuring storage changes because of difficulty in measuring flavor deterioration.

Clouding and Sedimentation. A problem encountered in clarified apple juice is the formation of cloud and sediment in the product during storage. Although the appearance of cloud and sediment is not always accompanied by deterioration of flavor or aroma, and is not necessarily a result of bacterial action, it does detract from the appearance of the juice and its presence is often taken by the consumer as an indication of spoilage. Its presence is particularly objectionable in juices packed in glass. The phenomenon first appears as a haze or slight cloudiness, which may become quite pronounced. The suspended particles gradually settle to form a compact layer, leaving the juice again clear. The problem has been particularly troublesome in juice clarified by means of pectic enzymes, though it is also encountered in juices clarified by other means. Numerous investigations have reported on clouding and sedimentation in apple juice, and several remedies have been suggested.[686,686a-686k,687]

[684] M. E. Heller, T. Nold, and J. J. Willaman, *Fruit Products J., 27,* 77, 87, 89 (1947).

[685] C. S. Pederson, H. G. Beattie, and E. H. Stotz, *N. Y. Agr. Expt. Sta. Bull., 728,* 1947.

[686] Z. I. Kertesz, *N. Y. Agr. Expt. Sta. Bull.,* 589, 1930, p. 9.

[686a] D. C. Carpenter and W. F. Walsh, *N. Y. Agr. Expt. Sta. Tech. Bull. 202,* 1932, pp. 16–17.

[686b] D. C. Carpenter, *Natl. Bottlers' Gaz., 52,* 50 (1933).

[686c] J. A. Clague and C. R. Fellers, *Mass. Agr. Expt. Sta. Bull.,* 336, 1936, p. 13.

[686d] H. D. Poore, *Fruit Products J., 14,* 170, 201 (1935).

[686e] F. W. Fabian and R. E. Marshall, *Mich. Agr. Expt. Sta. Circ.,* 98, (revised) 1935, pp. 12–13.

[686f] H. H. Mottern, *Western Canner and Packer, 29,* 12 (1937).

[686g] R. E. Marshall and J. C. Kremer, *Mich. Agr. Expt. Sta. Quart. Bull., 20,* 33 (1937).

A comprehensive study of this problem[688] indicated that the phenomenon was probably the result of colloidal instability rather than chemical action. Apple juices were subjected to a wide variety of special treatment but no dependable method for preventing sediment formation was found. Juices were observed to vary widely in the storage period required before sedimentation occurred, in some cases remaining clear for over two years, which may account for the discrepancies in the literature regarding methods of preventing its formation. Juices stored at 95°F. usually formed a sediment sooner and in greater quantities than when stored at room temperatures, while storage at about 38°F. delayed its formation and deposits were smaller. Restabilization of the colloidal system present in the juice, after clarification, offered the greatest hope for control of this problem. A chemical examination showed the sediment obtained from Winesap apple juice to be a rather inert subsance which agreed in its chemical properties with phlobaphenes.

Stabilization of the colloidal system in clarified apple juice by the addition of pectin after clarification was previously suggested as a means of delaying sedimentation[689] and pilot plant experiments[690] using added pectin have shown this method to be effective in commercial operations. The addition of from 5 to 10 ounces of nonacidulated, starch-free, liquid, apple pectin of 50 grade (about 5.7 grade according to present common usage) per 100 gallons of juice, before flash pasteurization has been recommended to reduce the sediment to negligible amounts.[691]

F. Concentration of Apple Juice

In recent years fruit juice concentrates have attained an increasingly important position in the food industry. This development

[686h] R. E. Marshall, *Fruit Products J., 16,* 328, 331 (1937).
[686i] M. A. Joslyn and G. L. Marsh, *Univ. Calif. Agr. Expt. Sta. Circ.,* 334, 1937, pp. 30–31.
[686j] D. K. Tressler and C. S. Pederson, *N. Y. State Agr. Expt. Sta. Circ.,* 181, 1938, p. 15.
[686k] V. L. S. Charley and T. H. J. Harrison, *Imp. Bur. Hort. Plantation Crops, East Malling, Kent, Tech. Commun., No. 11,* 9 (1939).
[687] H. H. Mottern, A. M. Neubert, and C. W. Eddy, *Fruit Products J., 20,* 36, 55, 57 (1940). J. Forgacs, W. A. Ruth, and F. W. Tanner, *Food Research, 10, 227* (1945).
[688] A. M. Neubert and M. K. Veldhuis, *Fruit Products J., 23,* 324, 347 (1944).
[689] H. H. Mottern, A. M. Neubert, and C. W. Eddy, *ibid., 20,* 36, 55, 57 (1940).
[690] R. E. Marshall, *ibid., 23,* 40 (1943).
[691] R. E. Marshall, *Food Packer, 27* (9), 49 (1946).

has been due, to a large extent, to the increased use of natural fruit products in fruit juice beverages. Concentrates have also become important products in the manufacture of marmalades, fruit butters, jams, jellies, and fermentation products of apples. An important advantage of the concentrated products is the considerable savings realized in shipping, container, and storage costs, and the greater stability of the concentrates to decomposition by microorganisms. In order to assure that the products will be stable against fermentation the soluble solids content must be brought to at least 65° Brix and the containers must be sealed against atmospheric moisture and oxygen to prevent mold growth.

1. CONCENTRATION BY EVAPORATION

Boiled Cider. Juice concentrated by boiling at atmospheric pressure develops a characteristic, burnt taste because the high temperatures required over the prolonged boiling period cause caramelization of the sugars present and the formation of other brown reaction products. Although the flavor is no longer typical of fresh juice, *boiled cider* is still used to a considerable extent in the manufacture of apple butter where the caramelized flavor is desired. Cloudy juice is commonly used in its preparation and the product is skimmed to remove coagulated solids during evaporation in open pans. The long boiling at high temperatures destroys much of the jellying properties of the pectin so the product is not apt to gel on cooling. Continuous concentrators have been designed for the preparation of this product. The juice flows through wooden flumes supplied with heating coils which boil the juice as it moves from one end of the flume system to the other.[692]

Low-Temperature Evaporation. To retain the natural flavor of fresh apple juice it is necessary to concentrate the juice by evaporation at temperatures sufficiently low to hold chemical changes to a minimum. This may be accomplished by subjecting the juice to blasts of air while heated to 150°F. or lower in a manner analogous to drying the sliced fruit and apparatus suitable for accomplishing evaporation at low temperatures under atmospheric pressures have been described in the literature.[693]

[692] R. W. Arengo-Jones, *Fruit Products J., 20,* 372 (1941).

[693] J. F. Ruff, Brit. Pat. No. 157,514, Oct. 6, 1919; *Chem. Abstracts,* 15, 1952. E. Bickel, *Destillateur u. Likörfabr, 50,* 474 (1937); *Chem. Abstracts, 31,* 8733.

Vacuum evaporators in a variety of types are, however, more commonly applied to the concentration of apple juice. Among the various evaporators used are single- and multiple-stage vacuum pans[694-696] employed in concentrating sugar sirups, milk, and similar

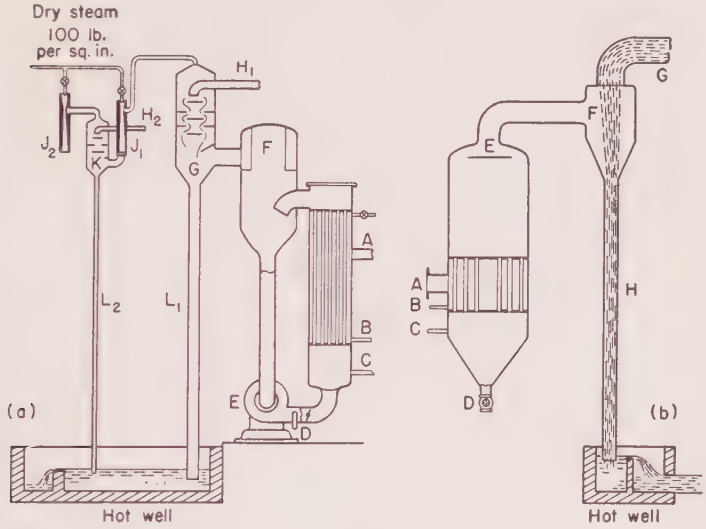


Fig. 83. (*a*) Single-effect, forced-circulation concentrator with a counterflow barometric condenser and a two-stage steam-jet evacuator.[693a] A, inlet for low-pressure steam; B, outlet for condensed steam; C, inlet for single-strength juice; D, outlet valve and tube for pumping out concentrate by choking the adjacent butterfly valve in the main circulating system; E, circulating pump; F, flash chamber equipped with a built-in spiral entrainment separator; G, counterflow barometric condenser; H_1 and H_2, condenser water inlets; J_1 and J_2, first and second stages of steam-jet evacuation; K, small barometric intercondenser; L_1 and L_2, barometric legs with minimum length of 35 ft. (*b*) Standard Claassen-type single-effect concentrator with multiple-jet condenser-ejector. A, inlet for low-pressure steam; B, outlet for condensed steam; C, single-strength juice inlet; D, outlet for concentrate; E, stack equipped with a baffle to minimize entrainment; F, multiple water-jet condenser; G, condenser water inlet; H, barometric leg with minimum length of 35 ft.

[693a] J. L. Heid, *Food Inds., 15* (5), 64 (1943).
[694] V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta. Long Ashton, Bristol, 1932,* 175 (1933).
[695] V. L. S. Charley, D. P. Hopkins, and A. Pollard, *ibid., 1940,* 97 (1941); *Fruit Products J., 21,* 262 (1942).
[696] H. H. Mottern, *Proc. Wash. State Hort. Assoc., 32nd Ann. Meeting, 1936,* 114; *Fruit Products J., 17,* 68 (1937).

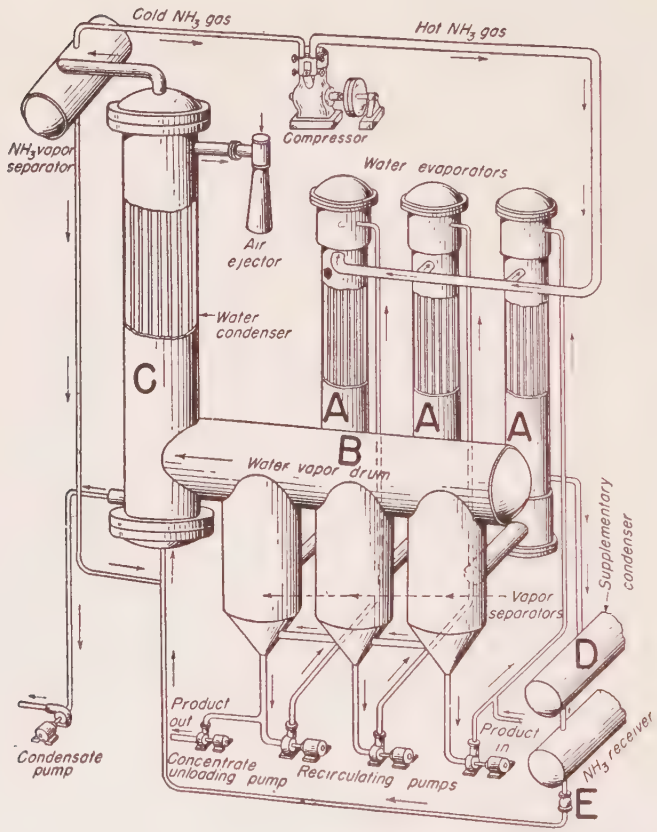


Fig. 84. Flow diagram of a recompression evaporation system concentrator.[699a] Heat, latent in the compressed ammonia vapor, causes juice to boil in shell and tube condensers (*A*). Water vapor from (*A*) is separated in drum (*B*), and passes into large shell and tube condenser (*C*). Ammonia, liquefied by exchange of latent heat in (*A*), is further cooled in condenser (*D*) and passes through expansion valve (*E*) where it is vaporized in condensing the water vapor. Ammonia vapor returns to compressor, completing the cycle.

products. Tubular and climbing film evaporators[697,698] and specially designed fruit juice concentrators have also been proposed. Recirculating the juice through a heating tube and expelling it into a vacuum

[697] V. L. S. Charley, *Chemistry and Industry*, *59*, 823 (1940).
[698] W. L. Badger, *Chem. & Met. Eng.*, *46*, 640 (1939).

chamber where the sensible heat of the juice causes sudden evaporation to take place has been suggested in order to reduce the time required for effecting concentration.[699] More recently a new type recompression evaporation system has been developed for the economical, low-temperature commercial evaporation of fruit juices.[699a] In this system ammonia is used as a heat-transfer medium, warming the juice in a three-stage, forced, falling film evaporator after the compression cycle and condensing the water vapor in an evaporation cycle (see Fig. 84). In general, the determining factor in the selection of evaporation equipment is that the evaporator be capable of evaporating water at the required rate while maintaining the juice at a suitably low temperature, preferably under 150°F., to avoid deleterious effects of heat on the product. Ease of operation and efficiency in the use of heat are also important considerations.

Volatile Flavor Recovery. One of the principal problems encountered in the concentration of apple juice by evaporation is the loss of volatile, aromatic flavor constituents, and concentrates prepared by atmospheric or vacuum evaporation are practically devoid of the characteristic aroma of fresh apple juice. In order to recover the volatile flavor consituents, the chemical identity of which has been discussed (Chapter X, page 256) special techniques have been developed. These volatile constituents have been observed to pass off with the first vapor to be removed from the juice[700,701] and it has also been noted that they may be trapped in concentrated sugar solutions. Among methods developed for recovering these flavor constituents one consists in passing the first vapors removed during the evaporation process through a cold concentrate obtained by previous evaporations,[702] whereas another consists of stripping the juice of aromatic constituents by a preliminary passage through a vacuum pan and condensing this first vapor for return to the final concentrate.[703] In both methods it is necessary that the concentration of the juice be

[699] H. H. Mottern, *Proc. Wash. State Hort. Assoc., 32nd Ann. Meeting, 1936,* 114; *Fruit Products J., 17,* 68–70 (1937).
[699a] J. A. Cross and A. V. Gemmill, *Food Inds., 20,* 1421 (1948).
[700] D. C. Carpenter, *Natl. Bottlers' Gaz., 52,* (620), 50 (1933); *Fruit Products J., 13,* 37 (1933).
[701] H. D. Poore, *ibid., 14,* 170, 201 (1935).
[702] D. C. Carpenter and E. C. Smith, *Ind. Eng. Chem., 26,* 449 (1934); *Fruit Products J., 13,* 223, 247, 251 (1934).
[703] V. L. S. Charley and B. N. Reavell, *Food, 8,* 427 (1939).

carried beyond that desired in the final product because of dilution by the aromatic fraction. A procedure for fractionally condensing most of the water from the vapor and allowing the volatile aromatic fraction to pass on to a secondary condenser maintained at low temperatures by means of salt–ice packs, where it is condensed in a relatively concentrated form, has also been proposed.[704] Excessive dilution of

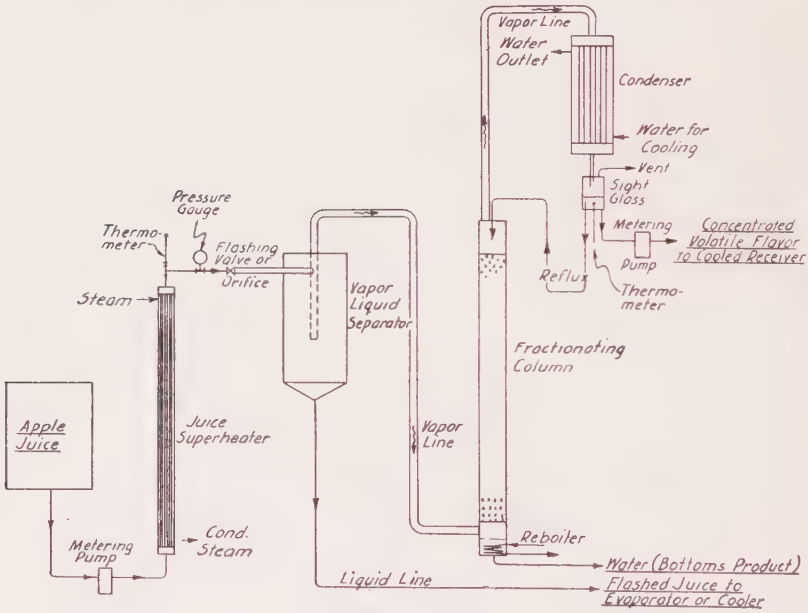


Fig. 85. Flow diagram of process for recovering volatile apple flavor.[705]

the concentrate is avoided by this method, but some of the aromatic constituents are lost in the water condensate.

No doubt the most efficient process for recovering the volatile flavor constituents from apple juice is the recently developed process of stripping these substances from juice by heating in a rapid evaporator to obtain a 10% flash vaporization which removes all of the volatile substances.[705] The condensate is then treated in a fractional

[704] H. H. Mottern, *Proc. Wash. State Hort. Assoc., 32nd Ann. Meeting, 1936,* 114; *Fruit Products J., 17,* 68 (1937).

[705] H. P. Milleville and R. K. Eskew, *Agr. Ind. Chem. Bur., U. S. D. A. Pub.* AIC-63, Sept. 1944; and suppl. 1, Apr. 1945; *Fruit Products J., 24,* 48 (1944); *Food Packer* (12), *25,* 33, 50 (1944).

distillation column where the volatile flavoring constituents can be concentrated up to 150 times that of the original juice at atmospheric pressures. The chemical composition of an apple essence is given on page 257.

The freshness of the volatile flavors, after they are separated from the juice, are not affected by prolonged exposure to the temperature of boiling water. The more complete removal of volatile constituents which is obtained by the rapid evaporation, and their subsequent enrichment through fractional distillation make it possible to prepare full-flavored apple juice concentrates which, when reconstituted with water, are indistinguishable in taste and aroma from fresh apple juice. This process for recovering and concentrating the volatile, fragrant constituents of apples promises to be a practical method for the commercial preparation of volatile fruit concentrates from a variety of fruits. Essence preparations are useful in enriching the flavor of candy, jelly, and other foods as well as in preparing full-flavored juice concentrates. In the United States apple essence manufacture is subject to regulation by the Bureau of Internal Revenue, Treasury Department, because minute traces of alcohol usually present in the juice are concentrated to above 0.5%, by volume, of essence.

In a comparison of the volatile concentrates obtained from nine varieties of apples it was found that the aroma of each essence is characteristic of the variety from which it is produced and varieties differ considerably in the quality of the essence that may be recovered.[706] McIntosh, Red Delicious, Grimes Golden, Stayman, and Jonathan varieties yielded the most desirable concentrates, though blends of several varieties were considered superior to that obtained from the juice of any single variety. No doubt the condition of the fruit at the time of processing also has a pronounced effect on the quality of the product obtained.

2. CONCENTRATION BY FREEZING

When the temperature of apple juice is lowered below the freezing point, water separates in the form of ice crystals, leaving the dissolved constituents in an unfrozen, concentrated state. By removal of the ice crystals from the nonfrozen constituents it is possible to effect a concentration of the juice. The process of concentration by

[706] E. L. Griffin, F. B. Talley, and M. E. Heller, *Fruit Products J., 27,* 4, 27 (1947).

freezing avoids the danger of damaging the flavor of the juice by heat, and losses in volatile, aromatic constituents are held to a very low point.[707-714] Concentrated products obtained by this method have been found to be far superior in the retention of a fresh apple flavor than those obtained by the usual vacuum evaporation procedures.

Extensive commercial development of freezing concentration has been handicapped because of difficulties in practical application and the cost of the process. Several repetitions of the freezing and ice removal steps are required to accomplish concentrates up to 50° Brix. The thick consistency of a 50° Brix concentrate at the low temperatures required for freezing makes further concentration without undue loss of solids impractical. Somewhat greater concentrations may be realized by removal of the pectic material which contributes largely to this consistency and by improved methods of recovering the sirup from the ice mass. Separation of concentrate from ice by centrifuging or hydraulic pressure has been found to give a greater percentage of high degree concentrate than draining, but draining yielded the highest degree concentrate.[714a] The temperature at which concentrate is separated from ice also affects the degree of concentration that can be obtained in a single freezing. Separations made at 14–18°F. resulted in concentrates containing about 45% soluble solids in a single freezing; at —8°F., 55% soluble solids concentrates; and at —28°F., 60% soluble solids concentrates were obtained. Separation temperatures below 0°F. were considered impractical, however, because of difficulties in handling the ices.

Numerous types of equipment have been proposed to overcome the practical difficulties encountered in commercially concentrating apple juice by freezing. The Krause process,[715,716] used to a considerable extent in Europe, utilizes controlled freezing whereby the water

[707] H. C. Gore, *U. S. D. A. Yearbook, 1914,* 227.
[708] H. C. Gore, *Fruit Products J., 1* (11), 16 (1922).
[709] O. Grove, *Ann. Rept. Univ. Bristol Agr. and Hort. Research Sta. 1930,* 209 (1931); *Fruit Products J., 13,* 74, 89 (1933).
[710] M. A. Weber, *Food Inds., 3,* 187 (1931).
[711] V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1935,* 150 (1936); *Fruit Products J., 16,* 6 (1936).
[712] T. N. Morris, *Chemistry & Industry, 56,* 615 (1937).
[713] P. Bilham, *Fruit Products J., 17,* 360, 373 (1938).
[714] W. V. Cruess, *ibid., 21,* 165, 187, 190 (1942).
[714a] C. S. Pederson and H. G. Beattie, *N. Y. Agr. Expt. Sta. Bull., 727,* 1947.
[715] L. Engelhardt, *74th Conv. Assoc. German Eng. in Darmstadt,* 1936.
[716] P. Bilham, *Chemistry & Industry, 57,* 589 (1938).

is crystallized as needles arranged radially in the form of a ring. The frozen ring is then transferred to a centrifuge where the concentrate is thrown from the frame of ice. Due to the favorable arrangement of the ice crystals, greater efficiency in separating concentrate from ice, as well as higher concentrations, are realized than is possible when the ice is frozen into a slush.

Equipment designed to continuously expel ice from juice in the form of snow has also been developed.[717] The process involves the continuous freezing, by means of a refrigerated gas, of water from juice within a rotating shell which acts as a centrifuge, discharging partially concentrated juice from the periphery while the snow is removed by the action of an internal screw conveyor. In another continuous method the periphery of a revolving, internally refrigerated drum dips into a tank of juice, causing ice to form on its outer surface. As the drum revolves the ice and adhering juice are removed by scrapers and conveyed to a continuous centrifuge where residual juice is expelled.[718] A screw-type press has also been developed for removing juice adhering to the ice crystals.[719] Pressures of about 4000 pounds per square foot are developed. An earlier process consisted simply of removing the ice from the revolving, refrigerated drum by means of scrapers and recovering the concentrate remaining in the tank.[720] More recently a simple, continuous freezing concentration process has been developed which employs controlled ice crystal growth to obtain efficient separation of ice and concentrate.[719a] In this process ice crystals, formed by refrigerating the juice, are moved progressively from the more to the less concentrated juice by moving screens.

A process involving a preliminary concentration by freezing followed by surface evaporation has been developed to produce concentrates of high soluble solids.[721] Initial concentration to from 45 to 55% solids is accomplished by conventional methods of freezing concentration. The partially concentrated juice is then subjected to slow evaporation in a stream of heated gas. Loss of volatile, aromatic constituents is repressed by the relatively high concentration of soluble solids throughout the evaporation process.

[717] W. M. Zorn and T. H. Eickhoff, U. S. Pat. No. 1,999,712, April 30, 1935.
[718] F. Bazzi, U. S. Pat. No. 2,082,439, June 1, 1937.
[719] G. A. Krause, German Pat. No. 695,265, July 25, 1940; U. S. Pat. No. 2,241,726, May 13, 1941.
[719a] T. R. Olive, *Food Inds., 20,* 1432 (1948).
[720] E. Monti, *Cultivatore, 75,* 573 (1929).
[721] G. A. Krause, U. S. Pat. No. 2,248,634, July 8, 1941.

3. EFFECT OF CONCENTRATION ON JUICE CONSTITUENTS

Chemical Changes. Chemical changes occurring during concentration that might serve to identify products prepared from apple juice concentrate from those prepared from the fresh juice have been investigated.[722] Results of this study indicate that with certain precautions juice can be concentrated, either by vacuum distillation or by freezing, and rediluted without seriously affecting its chemical composition. Ordinary vacuum distillation must be supplemented by a process for returning the volatile, aromatic fraction to the concentrate. Changes in viscosity and alcohol-insoluble fractions were most pronounced in juice concentrated by freezing. Concentration by evaporation at 140°F. to a soluble solids content of 72% did not result in an inversion of sucrose, and concentration by freezing did not affect the mineral content of the product. Darkening and undesirable flavor changes have been observed, however, in concentrates of 70° Brix or higher during storage at room temperature.[723]

Gel Formation. A serious problem in the preparation of apple concentrates is gelling of the product. This occurs in some juices after concentration to 55% total solids while in others gels form only after concentration to above 71%,[724] depending on the variety of apples and their condition when pressed. The use of 10% immature fruit has been suggested[725] as a means of preventing gelling at high concentration. The most effective treatment for preventing gelling is by treatment of the juice with pectin-decomposing enzymes. Juice treated in this way loses most of the pectinous material and may be concentrated to a soluble solids content of 80% without gelling.[726,727]

4. APPLE SIRUPS

Apple sirups differ from concentrated apple juice by the fact that the process of preparation includes a treatment that changes the

[722] A. M. Neubert, *Fruit Products J., 23,* 166 (1944).
[723] W. V. Cruess, *ibid., 21,* 165, 187, 190 (1942).
[724] D. C. Carpenter and E. C. Smith, *Ind. Eng. Chem., 26,* 449 (1934); *Fruit Products J., 13,* 233, 247, 251 (1934).
[725] R. W. Arengo-Jones and W. Ferguson, *Natl. Bottlers' Gaz., 53* (636), 54, 58, 60 (1934); *Chem. Abstracts, 29,* 3768.
[726] H. D. Poore, *Fruit Products J., 14,* 170, 201 (1935).
[727] V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1939,* 116 (1940).

relative composition of the constituents present. It can therefore no longer be rediluted to yield a juice similar to that from which it was prepared (page 314). Numerous treatments are used to change the properties of the concentrate but they usually involve a reduction in acidity, either by the addition of sugar to the juice or by neutralization of a part of the acid. Sirups are intended for use in the concentrated form as table sirups or as sweetening agents where the unpalatably high acid content of concentrated apple juice is not desired. It is desirable that sirups prepared for table use retain a characteristic apple juice aroma and flavor but this requirement need not be met for products intended as substitute sweetening agents, or in industrial products where flavor is not an important factor.

Apple juice has a mild, delicate flavor and therefore sirups prepared by adding sugar to the desired soluble solids content do not have the appeal of sirups obtained from certain highly flavored fruits, such as raspberries or dewberries, for instance. Sirups to which sugar is added are usually prepared by partially concentrating the juice to increase its flavor. One process[728] involves adding an equal weight of sucrose to apple juice and heating the solution to accomplish inversion of the added sugar and concentration to 72% soluble solids, whereas in another sugar is added to 50% soluble solids and the resulting sirup concentrated up to 75% soluble solids by evaporation at atmospheric pressure in a current of warm air.[729]

The most common procedure for preparing apple sirup is to neutralize part of the acid in the juice, usually by means of alkali metal carbonates, calcium carbonate, or calcium hydroxide.[730-733] This may be accomplished before the juice is concentrated or after partial concentration. The use of calcium hydroxide to accomplish clarification as well as neutralization of acidity has been developed on a commercial scale in the production of sirups for use in industry as a humectant.[734,735] The process involves treating apple juice with a

[728] C. W. Haines, U. S. Pat. No. 1,965,286, July 3, 1934; *C.A., 28,* 5552.
[729] D. V. Wadsworth and L. Wickenden, U. S. Pat. No. 2,087,077, July 13, 1937.
[730] H. C. Gore, *U. S. D. A. Yearbook, 227,* 1914.
[731] H. C. Gore, U. S. Pat. No. 1,141,458, June 1, 1915; *Chem. Abstracts, 9,* 1952.
[732] H. D. Poore, *Fruit Products J., 14,* 170, 201 (1935).
[733] V. L. S. Charley, D. P. Hopkins, and A. Pollard, *ibid., 21,* 300 (1942).
[734] M. A. Bradshaw and H. H. Mottern, *U. S. D. A. Pub.,* ACE-189; *Fruit Products J., 21,* 356 (1942).
[735] H. H. Mottern and R. H. Morris, 3rd, *U. S. D. A. Pub.,* AIC-37, 1944; *Fruit Products J., 23,* 261, 283, 284 (1944).

calcium hydroxide slurry to a *p*H from 8.0 to 8.5, heating to 175°F. for a short period, and filtration, after which the juice is reacidified and concentrated under vacuum. The product obtained by this process is amber in color, very sweet and bland, with a bitter aftertaste. Its consistency is about that of an invert sirup of the same solids content.

One of the principal difficulties in preparing sirups for table use by neutralizing the acid is a bitter flavor imparted to the juice from the malic acid salts formed. A recently developed process for obtaining a sirup of pleasing flavor employs an ion-exchange treatment to remove malic acid before neutralization.[736] Arsenic residue was not effectively removed from juice, however, unless a three-step treatment involving passage of the juice successively through cation, anion, and cation exchangers was used. The flavor of apple sirups may of course be enhanced by addition of concentrated aromatic constituents.

Apple Treackle. Apple *treackle* is produced by evaporating apple juice to a very high soluble solids content after partial neutralization of the acid. Gelling is prevented as effectively by partial neutralization of the acid as by enzyme decomposition of the pectin materials.[737,738]

Drying Apple Juice. Numerous workers have investigated the possibility of producing apple juice in powder form. The juice is usually concentrated, either by freezing or evaporation under vacuum, and the product subjected to further drying by spraying into hot gas.[739] Difficulties are encountered in preparing powdered apple juice because the product is highly hygroscopic. Special procedures are required in operating spray driers. If insufficient heat is applied the evaporation will not be complete, whereas excessive heat causes it to melt and stick to the walls of the drier. A practical solution to these problems will possibly involve the use of added agents to reduce stickiness. Dried apple juice must be packaged in hermetically sealed containers to prevent caking and stickiness.

[736] R. E. Buck and H. H. Mottern, *Ind. Eng. Chem., 37,* 635 (1945).
[737] O. Grove, *Ann. Rept. Agr. and Hort. Research Sta. Univ. Bristol, 1930,* 209 (1931); *Fruit Products J., 13,* 74, 89 (1933).
[738] V. L. S. Charley, D. P. Hopkins, and A. Pollard, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1940,* 97 (1941); *Fruit Products J., 21,* 262 (1942).
[739] W. H. Dickerson, U. S. Pat. No. 1,562,309, Nov. 17, 1925; *Chem. Abstracts, 20,* 248.

CHAPTER XIII

FERMENTATION PRODUCTS OF APPLES

A. Introduction

On a world-wide basis more apples are used in the preparation of fermented beverages than in the manufacture of all other products combined. By far the most important beverage, on the basis of quantity of apples used, is pure fermented apple juice which is referred to simply as *cider* in countries other than the United States. In practically all apple producing countries except the United States and Canada cider is the main product prepared from apples. Whereas cider production is commercially unimportant in the United States, this country is the only important producer of *apple wine*. Apple wine is commonly differentiated from cider by its higher content of alcohol, obtained either by the addition of sugar to apple juice during fermentation or by the addition of alcohol after fermentation or both. *Apple brandy*, a distillation product of cider, is produced in considerable quantities in the United States and is used both for direct consumption and in fortifying apple wine. In Europe, France is the principal producer of apple brandy and large quantities are made for direct consumption. In addition to the fermented beverages prepared from apples, cider is used extensively on the North American continent in the production of *vinegar*, but cider vinegar is of minor importance in other countries.

The relatively high carbohydrate content of apples has directed considerable attention to the possibility of utilizing waste and surplus fruits in the production of fermented products for other than food uses. Although no technical difficulties are encountered in converting apple carbohydrates into industrial ethyl alcohol or acetic acid by fermentation process, economic considerations have not been favorable in this country for the use of this raw material in competition with sources such as molasses, the cereal crops, or petroleum, under a normal economy. Apple juice has also been used as a medium for the production of certain types of yeast and certain organic acids, but commercial

manufacture of such products is handicapped by the same economic considerations that apply in the manufacture of alcohol.

B. Cider

1. DEFINITION

As has been discussed under apple juice (Chapter XII), considerable confusion exists in the United States concerning the identity of cider. For the sake of clarity the term *cider* will be reserved, in this book, for the product of the normal alcoholic fermentation of apple juice which contains more than 0.5% and not more than 8% alcohol, by volume. Juice containing less than 0.5% alcohol will be considered to be apple juice and fermentation products containing more than 8% and less than 24% alcohol, by volume, will be considered to be wines. These definitions conform to general usage in most apple consuming countries and have the advantage that they permit differentiation between the several distinct types of beverages produced from apples. The definitions do not, however, conform to present usage in the United States where freshly pressed apple juice and juice preserved with sodium benzoate as well as fermented juice are frequently termed cider. Although Federal regulations[740] define as wine the product of the normal alcoholic fermentation of the juice of sound ripe apples, with or without the addition of sugar, these regulations do not preclude the manufacture and sale, free of tax, of the farm product known as apple cider, provided it is made and sold as plain cider. This product must be prepared without addition or subtraction, including manipulation to retain carbon dioxide, except that sugar may be added for sweetness after fermentation.

2. HISTORY AND PRODUCTION

The history of cider manufacture coincides with that of apple juice since alcoholic fermentation proceeds rapidly in the freshly pressed juice unless preservation methods are applied. During the early history of juice manufacture, preservation methods were unknown and it is safe to assume that most of the juice was consumed in the fermented form. This assumption may be further substantiated on the basis that early apple varieties were for the most part of the

[740] *Wine*, Bureau of Internal Revenue, U. S. Treasury Dept., *Reg. 7*, 1945, pp. 11–12.

wild or crab types that were not particularly suitable for dessert or fresh juice consumption but which made excellent cider. As the cider industry developed variety selections were made until a large assortment of distinct cider varieties now exist in European countries. These varieties are not suitable for consumption as fresh fruit or for culinary use, but are highly prized in the manufacture of cider.

In total production of apples France is exceeded only by the United States and it is estimated that nearly 95% of this production is of the cider varieties.[741] France produces an average of 630 million gallons of cider annually for consumption as cider, brandy, and industrial alcohol. From 20 to 25 million gallons are produced annually in England for consumption as cider, and Germany produces about 6 million gallons.[742] Most of the technology of cider manufacture has been developed by these countries. The Soviet Union, Poland, Switzerland, Czechoslovakia, Yugoslavia, Austria, and Italy also produce considerable quantities of cider apples, and industrial production of cider in Argentina is increasing.[743] In general, cider production in these countries is a small farm operation with most of the product consumed locally.

Production data for cider in the United States are not available because cider production statistics include unfermented apple juice. There is no record of the proportion of this production that is allowed to ferment before it is consumed. Cider, as a manufactured beverage, is of little importance in North America and the fermented apple juices produced differ from those of Europe and England because the special cider varieties used in their preparation are not grown commercially on the American continent.

3. TYPES OF CIDER

Ciders vary considerably in quality and character, not only because of differences in the varieties and the condition of the fruit used, but also in their method of preparation. Ciders have been classified

[741] *Imperial Economic Committee, Apples and Pears, a Survey of Production and Trade in British Empire and Foreign Countries.* H. M. Stationery Office, London, 1938.

[742] V. L. S. Charley and T. H. J. Harrison, *Imp. Bur. Hort. and Plantation Crops., East Malling, Kent, Tech. Commun. No. 11,* 74 (1939).

[743] J. Testa, *Univ. Buenos Aires, Facultad Agron, y vet. Inst. ind. Agr., (Enol. e ind. extractives) 1,* 93 (1943); *Chem. Abstracts, 38,* 1039.

into several types depending on this method of preparation and the character of the product.[744]

Sparkling Sweet Cider. Sparkling sweet cider is produced by fermenting apple juice just sufficiently to give effervescence, and contains not more than 1% alcohol by volume. Fermentation is conducted in a closed container and the various processing steps, including filtration and bottling are carried out in a closed system so that natural carbon dioxide, formed during fermentation, is retained to produce a carbonated product.

Sparkling Cider. Like sparkling sweet cider, sparkling cider is charged with gas produced by its fermentation. It differs from the sweet product in that fermentation is allowed to proceed until the product contains about 3.5% alcohol. Not all of the carbon dioxide formed during fermentation is retained in the finished product.

Sweet Cider. Apple juice may be partially fermented in open tanks to produce a *still* (noneffervescent) *cider* which retains sufficient sugar to make it sweet. Another method of producing a sweet cider is by the addition of sugar to the completely fermented juice.

Dry (Hard) Cider. Fully fermented apple juice is termed dry or hard cider. Sugar may be added before fermentation to raise the alcohol content of the final product to from 6 to 7%. The product resembles a still wine in that it is not effervescent and proper aging is necessary to obtain the characteristic cider flavor. Its alcoholic content is considerably lower than that commonly found in wine.

Carbonated Cider. The term carbonated cider is applied to any cider that has been charged with commercial carbon dioxide to produce effervescence. Carbonation at from 40 to 50 pounds per square inch may be used for dry ciders that are not highly acid.

Champagne Type Cider. Champagne type cider is produced in a manner similar to that employed in preparing champagne. Effervescence is produced in the final product by a secondary fermentation of the dry cider in bottles. Sugar and champagne yeast are added before bottling and the secondary fermentation is allowed to proceed very slowly.

4. APPLES USED

Varieties. Cider varieties differ from culinary or dessert apples mainly in their higher content of tannin or astringency. Usually

[744] R. W. Arengo-Jones, *Fruit Products J., 20,* 300, 321 (1941).

these varieties also possess a slightly higher content of sugar and a somewhat lower acidity than culinary varieties. In European countries certain varieties of cider apples have become recognized as especially suited to the making of certain types of cider in the same way that certain varieties of grapes are recognized as being particularly suitable for preparing special types of wine. Just as with wines, the quality of ciders is governed basically by the vintage value of the apples from which they are made. The maximum potential quality of

TABLE 41. AVERAGE CHEMICAL COMPOSITION OF JUICES OF SOME VARIETIES OF ENGLISH-GROWN CIDER APPLES[a]

Variety	Specific gravity	Acidity as malic acid, %	"Tannin," %
Vintage			
Kingston Black	1.060	0.68	0.24
Foxwhelp	1.048	0.70	0.24
Sharp			
Frederick	1.048	1.00	0.09
Cap of Liberty	1.050	0.85	0.22
Dymock Red	1.052	0.55	0.22
Sweet			
Sweet Alford	1.053	0.26	0.14
Woodbine	1.057	0.30	0.16
Bittersweet			
Knotted Kernel	1.060	0.38	0.35
Dabinett	1.053	0.20	0.25
Yarlington Mill	1.050	0.25	0.24
Medaille d'Or	1.053	0.25	0.45

[a] From V. L. S. Charley and T. H. J. Harrison, *Imp. Bur. Hort. and Plantation Crops, East Malling, Kent, Tech. Commun., No. 11,* 21 (1939).

a cider made from a given lot of fruit is predetermined when the apples are harvested. A number of factors in fruit handling and cider manufacture determine how nearly the finished cider approaches that maximum. Considerations involved in determining the vintage quality of apples have been reviewed in the literature.[744a]

Dessert and culinary apples are for the most part comparatively low in tannic acid and their juices lose both body and flavor in fermentation. Such varieties may, however, be used in blends with suitable

[744a] B. T. P. Barker and L. F. Burroughs, *Fruit Products J., 27,* 14 (1947).

TABLE 42. Summary of Analyses of Fruit of French-Grown French Cider Apples and French Cider Apples Grown at Blacksburg, Va.[a]

Variety	Total sugar, %	Acidity as malic acid, %	Total astringency, %	Solids, %
Amére du Surville				
French	12.20	0.350	0.0760	20.2
Blacksburg	9.48–12.40	0.464–0.778	0.570–0.760	19.92–23.65
Bedan des Parts				
French	12.61	0.360	0.170	21.60
Blacksburg	11.68	0.601	0.360	21.58
Binet Blanc				
French	16.48	0.380	0.150	19.70
Blacksburg	12.38	0.396	0.130	19.78
Binet Rouge				
French	11.93	0.25	0.160	20.5
Blacksburg	14.12	0.546	0.240	27.80
Julian de Paulmier				
French	11.86	0.330	0.160	22.00
Blacksburg	16.54	0.218	0.380	26.34
Launette Grosse				
French	14.52	0.270	0.550	21.50
Blacksburg	10.10–10.70	0.415–0.574	0.230–0.480	19.80–20
Maréchal				
French	13.50	0.330	0.500	22.2
Blacksburg	12.85	0.410	0.500	22.4
Michelin				
French	10.92	0.32	0.220	19.30
Blacksburg	13.05	0.725	0.290	23.92
Montlige Blanc				
French	11.60	0.290	0.210	19.80
Blacksburg	6.43	0.164	0.160	17.17
Moulin-à-Vent				
French	12.37	0.60	0.040	21.10
Blacksburg	11.27	0.410	0.410	20.65
Omont				
French	12.34	0.37	0.200	20.6
Blacksburg	13.60	0.232	0.210	22.26
Reine des Pommes				
French	12.96	0.570	0.240	19.90
Blacksburg	10.62–13.20	0.428–0.847	0.340–0.540	19.75–26.3
Rouge du Landel				
French	12.20	0.31	0.120	19.70
Blacksburg	8.09	0.53	0.200	17.55
St. Laurent				
French	13.88	0.21	0.210	25.50
Blacksburg	16.04	0.314	0.270	28.30

[a] From J. S. Caldwell, *J. Agr. Research*, *36*, 396 (1928).

cider varieties to make a *light cider*. A number of American workers have investigated the possibilities of producing cider from American varieties.[745–749] It is generally recognized, however, that the qualities

of cider apples are prerequisite to the making of fermented apple beverages of a type and quality comparable to the French product.

English cider varieties have been grouped into four types on the basis of the properties of the juice they yield. The average composition of the juice of representative varieties for each of these types is presented in Table 41. More recently, English cider apples have been divided into eight grades of sharp, sweet, and bittersweet.[750]

A number of cider varieties are grown experimentally both in Canada and the United States. Table 42 presents a summary of the analyses of the whole fruit of a number of French cider varieties as grown in France and in two sections of Virginia. These data show that juices comparable to the French product could be obtained in America if suitable varieties were used.

Blending. Blending is an important step in cider making as it is the basis of uniformity. Blending of the apples or fresh juice may be practiced in preparing ciders of low alcoholic content but blending of the fermented stock is preferable in preparing fully fermented cider because the effect of fermentation on fresh juice cannot always be accurately forecast. Special qualities have been found desirable in the juice used in preparing each of the several types of cider.

Juice for sparkling sweet cider should not be too sweet or too heavy in body. Astringency is less important than the correct sugar–acid balance, but it should not be above 0.1%. Juice with a specific gravity of 1.055, and containing from 0.5 to 0.6 gram of acid, as malic, and 0.06 to 0.1 gram of tannin, as tannic acid, per 100 cc. has been suggested as suitable for preparing sparkling sweet cider provided it possesses a good flavor.[751] Good quality sparkling sweet ciders have been prepared experimentally in Canada by blending about 25% of well-ripened McIntosh with Stark, Spy, or Ben Davis; by blending Golden Russet with Spy; or by use of Baldwin juice of less than 0.55% acid, as malic.

Juice used in preparing sparkling cider and the fully fermented types should be high in sugar, of moderate acidity, and fairly astringent. For maximum palatability it has been suggested that the

[745] W. B. Alwood, *U. S. D. A., Bur. Chem. Bull.,* 71, 1903.
[746] W. B. Alwood, J. R. Davidson, and W. A. P. Moncure, *ibid.,* 88, 1904.
[747] H. L. Price and W. B. Ellett, *Ann. Rept. Virginia Agr. Expt. Sta., 1908,* 39.
[748] W. A. Alwood, *U. S. D. A. Bur. Chem. Bull.,* 129, 1909.
[749] D. K. Tressler, R. F. Celmer, and E. A. Beavens, *Ind. Eng. Chem., 33,* 1027 (1941).
[750] E. Ball, *Chemistry & Industry, 1946,* 38; *Chem. Abstracts, 40,* 2553.
[751] R. W. Arengo-Jones, *Fruit Products J., 20,* 300, 321 (1941).

finished cider should contain from 0.5 to 0.6% fixed acids, as malic, from 0.1 to 0.15% tannin, and not over 0.08% volatile acids, as acetic.[751] In general, culinary and dessert varieties are unsuitable for the preparation of such ciders, though their juice may be used in blends with cider varieties, particularly of the bittersweet types. At least 20% juice of suitable bittersweet varieties has been found necessary for blending with selected dessert fruit to obtain a cider that has good body and flavor. Of varieties grown in Eastern Canada, only the Ribston and Nonpareil have been found to make acceptable cider without blending. Use of native Canadian varieties in blends with crab apple juice has also been reported to yield very satisfactory ciders.[752] Increased quantities of culinary or dessert varieties may be used with bittersweet apples if the juice of the market varieties is repressed with unpressed bittersweet pomace.[753] In preparing blends consideration must be given to seasonal variations in the composition of the different varieties if a uniform quality is to be obtained.

5. JUICE PREPARATION

Pressing. Methods described for crushing and pressing apples for apple juice (page 323) are employed in preparing juice for cider manufacture. The relation of pulping and pressing methods to quality of juice, as discussed in Chapter XII, apply equally in the manufacture of juice for cider. The practice of making a second pressing of the pomace is more common in the preparation of juice for cider than in making apple juice and extraction of residual sugars, tannins, and other constituents with water is also practiced. Experimental studies have shown that repressing the disintegrated pomace with the equivalent of three gallons of water for each 100 pounds of pomace yields an increased volume of extract which in may cases can be fermented separately to give ciders of soft, mellow astringencies.[754] Diffusion and a combination of pressing with diffusion may be used in large plants, particularly in producing alcohol, but pressing has been found to give better results because there is less danger of oxidizing the sugars.[755]

Maceration. A practice commonly followed in France in the

[752] W. Ferguson, *Sci. Agr., 15,* 557 (1935); *Chem. Abstracts, 29,* 6357.
[753] P. T. H. Pickford, *J. Bath, West and Southern Counties Soc. Encour. Agr., 10,* 194 (1935–36); *Chem. Abstracts, 30,* 8416.
[754] V. L. S. Charley and M. E. Kieser, *Ann. Rept. Natl. Fruit Cider Inst., Long Ashton, Bristol, 1940*; *Fruit Products J., 21,* 228 (1942).
[755] P. Bettinger, *Bull. assoc. chim., 55,* 388 (1938); *Chem. Abstracts, 32,* 5655.

preparation of cider is to permit the pulped fruit to stand for from 2 to 24 hours before pressing. This process, known as maceration, is considered to result in an increase in flavor, aroma, and color, and to give greater yields. The process requires rigorous control to avoid disadvantages such as loss of tannin and a tendency to induce acetification. The additional equipment and labor required for the maceration step may be held to a minimum if facilities are provided for draining the free juice from the shallow maceration tanks, thereby reducing the bulk of the material which must eventually be pressed. Maceration of the juice from culinary and dessert varieties for 12 hours with once-pressed pomace from bittersweet cider apples has been found to result in a decrease in the malic acid and tannin contents of apple juice, but to improve considerably the flavor of cider prepared from them.[756]

TABLE 43. Changes in Pectin and Other Constituents during Maceration[757]

Experiment No.	Length of maceration, hours	Juice expressed, cc.	Specific gravity of juice	Acidity, %	Tannin, %	Calcium pectate, %
C.1	0 (Control)	650	1.0538	0.83	0.12	0.227
C.2	0.5	660	1.0543	0.80	0.08	0.238
C.3	1	600	1.0545	0.82	0.08	0.243
C.4	2	660	1.0567	0.84	0.09	0.245
C.5	4	660	1.0551	0.83	0.08	0.290
C.6	6	670	1.0560	0.86	0.08	0.298
C.7	11	650	1.0554	0.90	0.08	0.298
C.8	24	655	1.0536	0.98	0.08	0.300
C.9	48	640	1.0511	1.00	0.09	0.289
C.10	72	620	1.0458	0.98	0.08	0.270
W.1	0	650	1.0133	0.12	0.005	0.170
W.2	0.5	650	1.0154	0.12	0.005	0.177
W.3	1	655	0.0157	0.12	0.005	0.187
W.4	2	650	0.0163	0.14	0.007	0.202
W.5	4	650	1.0181	0.16	0.009	0.236
W.6	6	645	1.0169	0.17	0.008	0.259
W.7	11	640	1.0169	0.22	0.010	0.301
W.8	24	645	1.0169	0.23	0.010	0.309
W.9	48	645	1.0143	0.23	0.011	0.289
W.10	72	640	1.0115	0.35	0.011	0.257

[756] P. T. H. Pickford, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1933,* 141.

[757] V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta., Natl. Fruit and Cider Inst., 1934; Fruit Products J., 15,* 304 (1936).

Results of an experimental study of the changes in pectin and other constituents during maceration are shown in Table 43. Experiments C.1 through C.10 show the changes in yield and properties of 600 cc. of Bramley's Seedling juice of tannin content 0.15% when macerated for increasing periods with 250 grams of a pomace which had yielded juice with 0.25% tannin content. Experiments W.1 through W.10 show the changes in the extract obtained when 600 cc. of water was macerated for increasing periods with 250 grams of the same pomace.

In this study the yield of juice obtained increased only during the first 6 hours of maceration and then declined. The specific gravity of the expressed juice increased until 11 hours had passed and fermentation had set in, whereupon the specific gravity decreased. The tannin content of the macerated juice was lower than the original juice, even though it was macerated with a pomace that had yielded juice high in tannin. It was therefore assumed that some of the tannin from the juice was fixed on the pomace and removed from solution. In a later study[758] this worker suggested that the tannin was converted during maceration into an oxidized form which does not reduce permanganate but which still contributes an astringency to cider. Oxidation of tannin during maceration was inhibited by the addition of sodium chloride. The pectin content of juice continually increased during maceration over a period of 24 hours. Ciders prepared from the various lots of juice shown in Table 43 were found to be thin and rough in flavor until maceration had been continued for 6 hours, whereupon the flavor became softer and fuller. After 24 hours or more of maceration the flavor became noticeably harsh in character.

Keeving. It is a common practice in France to hold the expressed juice in large shallow vats, with a considerable area of the juice exposed to the air, for 3 to 8 days during which extensive coagulation of pectic and protein materials occurs. This process, known as *keeving*, is a useful step in clarification and permits more ready filtration of the fermented juice. After the desired coagulation has taken place the juice is *racked* away from the solids that accumulate at the top and bottom of the vat for final fermentation. Juices stored for one week at 35°F. were found to be considerably clearer than corresponding samples stored at 48°F., especially when culinary varieties

[758] V. L. S. Charley and M. E. Kieser, *Ann. Rept. Natl. Fruit Cider Inst., Long Ashton, Bristol, 1940*; *Fruit Products J., 21,* 228 (1942).

were used in the blend.[759] Coagulation has been reported to be more rapid at 104° to 118°F. than at 63°F., and is favored by the addition of barley malt.[760] The keeving process has been replaced in many localities by use of enzyme preparations for effecting clarification (p. 394), or by use of supercentrifuges. Keeving has been found to remove from 40 to 60% of the total nitrogen, resulting in a more slowly fermenting juice in which fermentation often stops while the cider is still sweet.[761]

6. FERMENTATION

The word *fermentation*, as applied to the beverage industry, refers to the process whereby sugars are converted into ethyl alcohol and carbon dioxide by the action of yeast.

An interesting study has been reported on the fate of sugars present in apple juice during fermentation.[762] The average composition of apple must was: fructose 62.5, sucrose 20.0, and glucose 17.5, each expressed as per cent of the total sugars, and the specific rotation of the mixed sugars was —35.6°. During fermentation the sucrose was rapidly inverted and none remained when 50–60% of the total sugar had been fermented. In the early stages of fermentation approximately equal quantities of fructose and glucose were fermented to give a selective fermentation in which the glucose–fructose ratio approached zero because of the lower initial glucose content. Thus fructose was practically the only sugar remaining in fermented ciders. When sucrose was added before fermentation the various sugar ratios were changed but the added sucrose was also rapidly inverted during fermentation.

Methods of Fermentation. The manufacture of cider is concerned with promoting the fermentation reaction under controlled conditions so that the sugars are converted into alcohol to produce a palatable beverage with a minimum of undesirable side reactions. Fermentation may be accomplished in one of three general ways.[763]

[759] V. L. S. Charley, *J. Bath, West and Southern Counties Soc. Encour. Agr., 10,* 222 (1935–36); *Chem. Abstracts, 30,* 8509.

[760] E. Kayser and H. Delaval, *Compt. rend., 180,* 1966 (1925); *Chem. Abstracts, 19,* 3347.

[761] J. Tavernier and P. Jacquin, *Chimie & industrie, 56,* 104, 113 (1946); *Chem. Abstracts, 41,* 1067.

[762] G. Warcollier and A. Le Moal, *Ann. fals et fraudes, 28,* 517 (1935); *Chem. Abstracts, 30,* 805.

[763] B. T. P. Barker, *J. Inst. Brewing, 28,* 517 (1922); *Chem. Abstracts, 16,* 4005.

Natural or spontaneous fermentation, still the most important industrial method, depends on the presence of naturally occurring yeasts in the juice to accomplish conversion of the sugar into alcohol. Besides the desired yeast, torulae and a heterogeneous collection of undesirable fungi and bacteria occur in apple juice. During cider making there is a continuous struggle in progress between the yeast capable of producing a sound type of alcoholic fermentation and undesirable yeasts and bacteria. When there is present sufficient good yeast which is active to keep the liquor nearly saturated with carbon dioxide, risk of serious deterioration from bacterial development is not great.

Dominant fermentation by desirable yeasts may be assured by the addition of a culture of selected yeast to freshly pressed juice. Removal of large numbers of organisms by centrifuging, followed by the addition of a culture of selected yeast, is another procedure used to encourage a desirable type of fermentation. The addition of sulfur dioxide to wine and ciders in amounts sufficient to discourage undesirable fermentations but permit more tolerant desirable yeasts to proceed has been found useful in obtaining controlled fermentations.[764] Treatment with sulfur dioxide has been observed to result in a cider low in pectin whereas the use of calcium bisulfite or tartaric, citric, or malic acids has the reverse effect.[765] The use of sulfur dioxide has been found valuable in reducing the formation of volatile acids in wines.[766]

Pure fermentation involves preliminary sterilization of the fresh juice, followed by the addition of a pure yeast culture. Although this method assures that only the desired fermentation can proceed, treatments necessary to obtain a sterile juice may adversely affect the flavor of the product. For pure fermentations the juice may either be pasteurized by heating to 140° to 160°F., a process that sometimes affects the flavor; or chemical or physical means, such as the addition of sulfur dioxide, ozone, ultraviolet light, or formaldehyde, may be used. These later methods have not, however, met with any particular success. A special process which involves deaeration of the juice, heating to 158° to 167°F., for a sufficient period to effect sterilization,

[764] H. Müller-Thurgau and A. Osterwalder, *Landw. Jahrb. Schweiz., 28,* 480 (1914); *Bull. Agr. Intelligence, 7,* 977 (1915); *Chem. Abstracts, 10,* 797.
[765] G. Warcollier, *Cidrerie franc., 42,* (1930); *Bull. assoc. eleves inst. sup. fermentations Gand., 32,* 260 (1931); *Chem. Abstracts, 26,* 250.
[766] W. V. Cruess, *Fruit Products J., 15,* 324, 345 (1936).

and cooling to 104°F. by ebullition under vacuum has been proposed for the aseptic fermentation of apple cider.[767]

Fermentation Procedures. The procedure followed in fermenting apple juice varies with the processor and with the type of cider being made. In preparing sparkling sweet cider it is necessary to carry out the fermentation in a closed tank, *closed cuvee process,* capable of withstanding an internal pressure of about 75 pounds per square inch. Since it is desirable to have as much carbonation as possible with a minimum fermentation, the tanks are filled to leave only two or three inches of headspace. The tanks are supplied with a manhole, top outlet, bottom outlet, pressure gauge, safety valve, and liquid level indicator. When the pressure reaches about 50 pounds per square inch the cider is ready for processing. During fermentation the specific gravity of the juice drops about 0.007 and about 1% alcohol is present in the juice.

The closed cuvee process must be used during at least part of the fermentation in preparing sparkling ciders. Their preparation may be accomplished in one of several ways. It is possible to ferment the juice in a closed tank, removing the surplus carbon dioxide which may be recovered and used later in bottling, or the juice may be partially fermented in open vats and transferred to a closed tank for final fermentation under pressure. Another method, in which the natural fruity flavor is retained to a greater extent, consists in blending a partially fermented cider with fresh, clarified juice and allowing the final fermentation to proceed in a closed tank under pressure.

Carbonated ciders and hard or dry ciders are usually fermented in *open tanks.* Care must be taken to avoid acetification in the presence of atmospheric oxygen. There is less likelihood of undesirable bacterial changes if the tank is filled nearly full and partially closed so that the evolved carbon dioxide will sweep out atmospheric oxygen.

The evolution of carbon dioxide during fermentation by the open tank process tends to volatilize most of the aromatic, volatile flavor constituents from apple juice. In order to produce a full flavored cider the aromatic fraction may be removed by distillation before fermentation[768] or the juice may be fermented in a closed container supplied

[767] E. Barbet. *Chimie & industrie, Spec. No.,* 626 (May, 1924); *Chem. Abstracts, 18.* 3249.

[768] W. A. Rooker, U. S. Pat. No. 2,419,286, April 22, 1947.

with a suitable condenser to trap these constituents.[769] The condensed aromatic fraction is then returned to the cider after fermentation. Another process for retaining this fraction to a certain degree in partially fermented ciders consists in blending clarified, fresh juice with cider that has been fermented to dryness.

Control of Fermentation Rate. To obtain the best possible flavor cider is subjected to a slow fermentation. The rate of fermentation may be controlled by one or more of several procedures. The fermentation rate is commonly retarded by holding the temperature of the cider at from 60° to 65°F. Racking, whereby the yeast population is reduced, may also be employed to slow down fermentation when necessary. For the most rapid fermentation, apple juice is deficient in nitrogen and the rate and completeness of fermentation depends to a considerable degree on its nitrogen content. When nitrogenous substances are added to a slow fermenting juice the rate and completeness of fermentation is increased.[770-773] Conversely, fermentation may be retarded by decreasing the nitrogen content. It has been found possible to prepare a clear cider, containing considerable residual sugar, that is temporarily unfermentable by yeast.[774] The usual fermentation is started and then stopped by heating the juice to 113°F. The juice is then cooled, reinoculated with the same yeast, and fermentation again established. The fermentation is then stopped a second time by heating the cider. After repeating this process a third time the liquid becomes unfermentable. Ciders prepared in this way have been found to be depleted of nitrogen and phosphorus to a point where yeast cannot survive.[775] Ion exchange treatment, whereby the ash content of apple juice was reduced to 17% of its original value, has also been observed to stabilize apple juice through removal of nutrients necessary for growth of microorganisms.[776]

[769] H. Heuser, U. S. Pat. No. 2,034,468, March 17, 1936; *Chem. Abstracts, 30,* 3162.
[770] T. P. Barker, *J. Agr. Sci., 3,* 1; *Chem. Abstracts, 3,* 931 (1909).
[771] K. A. Gren, *Ber. Kgl. Lehranst. Wein Obst Gartenbau, Geisenheim-am-Rhien, 1906,* 218; *Biochem. Centr., 8,* 150; *Chem. Abstracts, 3,* 2030.
[772] O. Grove, *Ann. Rept. Agr. and Hort. Research Sta., Univ. Bristol, 1919,* 20; *Chem. Abstracts, 15,* 2957.
[773] H. E. Goresline, E. A. Beavens, and A. L. Curl, *Fruit Products J., 20,* 10 (1940).
[774] Boulard, *Compt. rend., 182,* 1422 (1926); *Chem. Abstracts, 20,* 3058.
[775] S. C. Vandecavey, *J. Agr. Research, 37,* 43 (1928).
[776] S. W. Challinor, M. E. Kieser, and A. Pollard, *Nature, 161,* 1023 (1948); *Chem. Abstracts, 42,* 6953 (1948).

Fermentation may be arrested or retarded by centrifuging,[777] the efficiency of the treatment increasing as fermentation approaches completion. A study of fermentation control by means of centrifuging has shown that the effectiveness of this treatment is related to the nitrogen content of the fresh juice.[778] High nitrogen juices, 0.018%, responded to centrifuging to a lesser degree than those with lower nitrogen content. With low nitrogen juices, 0.0053%, a single centrifuging at a low gravity was found sufficient to retain cider in a stable condition. Centrifuging juices direct from the press removed variable amounts of nitrogen, while passage of fermented ciders through a centrifuge removed up to 96% of the nitrogen.

Another study reported that the reduction of the nitrogen content of partially fermented cider to from 0.15 to 0.20 gram per liter, by filtration through a bag filter after the addition of kieselguhr or through asbestos or paper pulp filters, resulted in almost complete stoppage of fermentation.[779] Treatment with ultraviolet light has been used to arrest fermentation.[780] Sulfur dioxide may also be used to retard the rate of fermentation, when used either alone or in conjunction with centrifuging.[781]

7. CLARIFICATION

Ciders are marketed in a clear condition and considerable attention has been given to methods of clarification (*defecation*) whereby the filtration process may be facilitated and simplified. Filtration of ciders is usually not as difficult an operation as filtration of fresh juice because of changes occurring in the pectic constituents during the fermentation process. These changes may in some cases result in complete natural clarification.

Natural Clarification. When keeving is employed in preparing the juice, some clarification is realized through natural coagulation of

[777] B. T. P. Barker and O. Grove, *Ann. Rept. Agr. and Hort. Research Sta., Univ. Bristol, 1930,* 199. V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1933,* 145.

[778] V. L. S. Charley, *J. Bath, West and Southern Counties Soc. Encour. Agr., 13,* 152 (1938–39); *Chem. Abstracts, 33,* 7951.

[779] E. Dauthy and G. Abadie, *Bull. assoc. chim., 53,* 523 (1936); *Chem. Abstracts, 30,* 5719.

[780] Maurain and G. Warcollier, *Compt. rend., 149,* 155 (1909); *Chem. Abstracts, 3,* 2484.

[781] V. L. S. Charley and P. T. H. Pickford, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1940; Fruit Products J., 21,* 132, 153 (1942).

TABLE 44. Loss of Soluble Pectin during Normal Fermentation of Apple Juice[a]

Variety of apple	Analysis of fresh juice					Calcium pectate, % in fermenting juices			
	Specific gravity	Acidity, %	Tannin, %	Date of pressing	Calcium pectate, % in fresh juice	After 5 days	After 14 days	After 23 days	After 6 months in bottle
Early season									
Sour Natural	1.056	0.45	0.16	31.10.33	0.0988	0.0781	0.0512[b]	Trace	—
Improved Pound	1.061	0.23	0.15	31.10.33	0.0574	0.0510	0.0382[b]	Trace	—
Hangdown	1.061	0.16	0.19	31.10.33	0.1780	0.1107	Trace[b]	—	—
Blumen	1.054	0.26	0.19	31.10.33	0.1416	0.0721	Trace[b]	—	—
Knotted Kernel	1.074	0.23	0.33	31.10.33	0.1302	0.0721	Trace[b]	—	—
Late season									
Sharp									
Kingston Black	1.067	0.72	0.23	27.11.33	0.0924	0.0573	0.0201	—	Trace
	1.063	0.72	0.21	27.11.33	0.0444	0.0219	Trace	—	Nil
Woolston Spice	1.045	0.46	0.13	27.11.33	0.0552	0.0456	0.0252	—	—
Barn Door	1.062	0.83	0.28	27.11.33	0.0446	0.0432	0.0228	—	—
Layne's Colonels	1.060	0.75	0.22	27.11.33	0.0600	0.0510	0.0264	—	—
White Bache	1.061	0.77	0.18	28.11.33	0.0704	—	0.0160	0.0139	—
Normington	1.064	0.47	0.34	28.11.33	0.0832	—	0.0156	0.0143	—
Lambrook Pippin	1.066	0.62	0.32	28.11.33	0.0688	0.0480	0.0156	0.0143	Trace
White Sharp	1.058	0.64	0.17	29.11.33	0.0592	—	0.0190	0.0100	—

Variety of apple	Analysis of fresh juice: Specific gravity	Acidity, %	Tannin, %	Date of pressing	Calcium pectate, % in fresh juice	Calcium pectate, % in fermenting juices: After 5 days	After 14 days	After 23 days	After 6 months in bottle
Sweet									
Woodbine	1.053	0.18	0.13	27.11.33	0.0920	0.0556	Trace	—	—
Woodbine (Kittisford)	1.069	0.34	0.20	30.11.33	0.1096	—	0.0473	0.0413	0.0237
Smith's Sweet	1.066	0.26	0.19	27.11.33	0.0640	0.0480	0.0164	0.0154	Trace
Sweet Coppin	1.050	0.28	0.13	27.11.33	0.0840	0.0630	0.0506	0.0381	0.0101
Doux Amer	1.046	0.28	0.19	29.11.33	0.0488	0.0168	0.0108	—	Trace
Bittersweet									
Harry Master's Jersey	1.060	0.25	0.23	27.11.33	0.0744	0.0148	Trace	—	—
Green Bittersweet	1.062	0.22	0.21	27.11.33	0.0704	0.0332	0.0304	0.0101	—
Sweet Clusters	1.060	0.20	0.20	27.11.33	0.0784	0.0504	0.0268	—	—
Shrawley Bittersweet	1.067	0.32	0.48	27.11.33	0.1040	0.0988	0.0452	0.0314	Trace
Slack-ma-Girdle	1.062	0.27	0.20	27.11.33	0.0628	0.0396	0.0196	—	—
Michelin	1.047	0.22	0.24	29.11.33	0.0584	—	0.0150	0.0138	Nil
Tardive Forestier	1.053	0.28	0.37	29.11.33	0.0652	—	0.0208	—	—
Frequin	1.047	0.24	0.43	29.11.33	0.0224	—	0.0104	0.0102	—
Harry Master's Jersey	1.052	0.22	0.27	29.11.33	0.0516	—	0.0396	—	Trace

[a] From V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta., Natl. Fruit and Cider Inst., 1934*; *Fruit Products J., 15*, 304 (1936).

[b] Indicates calcium pectate after 9 days only.

suspended solids. Changes occurring in the colloidal system of apple juice during fermentation are variable and not completely understood, but decomposition of pectic substances is one of the most pronounced effects. Data from a study of pectic changes during normal cask fermentation of a number of ciders are presented in Table 44. Data in this table show that the rate of decomposition of soluble pectin in the fermenting juice is rapid, and that many juices retain only small quantities of soluble pectin, as determined by the calcium pectate method, after 14 days. Higher values were reported when the alcohol precipitate method was used for determining pectin. From these studies it was considered doubtful that soluble pectin compounds included in the calcium pectate analysis could be of any considerable importance from the standpoint of flavor. Further experiments indicated that these pectic changes probably resulted from the combined action of the yeast and naturally occurring enzymes in the juice itself. Juices which were sterilized by filtration and then inoculated with a number of different, pure yeast cultures showed a marked decrease in soluble pectin during fermentation, while similar juices flash pasteurized after sterile filtration showed no loss of pectin over a 50-day period.[782]

Enzyme Clarification. The use of pectin-splitting enzyme preparations, added to the freshly pressed juice before fermentation or during actual fermentation, is becoming increasingly important as a means of clarification. The addition of such enzyme preparations has the advantage of positive, dependable clarification as compared with the variable results obtained when fermentation alone is depended upon. Pectin-splitting enzymes and their use in clarification have been discussed in Chapter XII. Their method of application in cider manufacture is similar, but smaller quantities of enzyme may be used because the need for rapid action is not so great in the treatment of ciders.

Other Clarification Treatments. The various clarification methods outlined in Chapter XII have been applied in the manufacture of cider. Passing fermented ciders through a supercentrifuge is becoming increasingly important and in some cases may produce a product sufficiently clear to make filtration unnecessary. Treatment of cider with an extract of oak wood has also been proposed as a means of clarifying and improving cider.[783] A mixture of albumin, tannin,

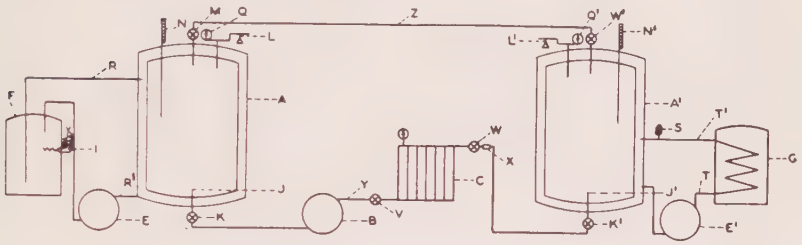
[782] V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1934*; *Fruit Products J., 15,* 329, 343 (1936).

[783] A. Jarraud and J. Roussel., Brit. Pat. No. 148,829, July 10, 1920; *Chem. Abstracts, 15,* 290.

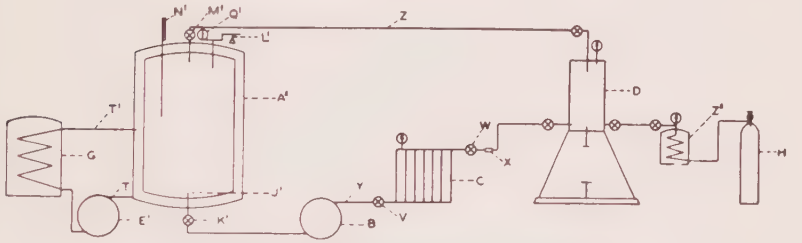
and a colloidal silicate such as bentonite has also been used to effect clarification.[784]

8. FILTRATION

Still Cider. Equipment and procedures outlined in Chapter XII for apple juice are commonly used in the filtration of uncharged cider.



Flow sheet for rough filtration of sparkling cider into chilling tank



Flow sheet for sterile filtration and bottling of sparkling cider

Fig. 86. Arrangement of equipment for making sparkling cider.[749]

A,A'	Jacketed glass-lined tanks
B	Portable rubber-lined rotary pump
C	Seitz-Werke improved multiplate filter
D	Isobarometric bottling machine
E,E'	Bronze centrifugal pumps
F	Water tank
G	Refrigeration (ammonia expansion)
H	Compressed CO_2 tank with reducing valve
I	Electric immersion heater and thermostat
J,J'	Silver-plated standpipes (1.25 inches)
K,K'	Monel metal globe valves (1.25 inches)
L,L'	Safety valves set at 120 lb.
M,M'	Bronze globe valves (1 inch) for isobarometric connections
N,N'	Thermometer (mercury) in silver-plated wells
Q,Q'	Pressure gage (1–100 lb.)
R,R'	Pipe lines (0.5 inch) for water circulation in jacket *A*
S	Regulator on brine circulation system
T,T'	Pipe lines (1 inch) insulated for circulation in jacket *A*
V	Inlet valve on Seitz filter
W	Outlet valve on Seitz filter
X	Holder for silk fiber retainer attachment
Y	Heavy rubber pressure hose and connection (1 inch)
Z	Pressure hose for 150 barometric connections (0.5 inch)
Z'	Expansion coil for liquid CO_2

[784] J. C. Ghesquires, Fr. Pat. No. 835,530, Dec. 23, 1938; *Chem Abstracts, 33,* 4738.

TABLE 45. STORAGE TESTS ON CIDERS MADE BY CHECKED FERMENTATION METHODS[781]

Experiment No.	Date of making	Volume of juice, gallons	Original gravity of juice	Treatment[a]	Final gravity at end of experiment	Date of taking final gravity
4/39	1.11.39	1000	1.048	C* at 1.030 on 9.11.39	1.027, 1.022, 1.018, 1.018, 1.018, 1.010, 1.010	26.4.40
5/39	3.11.39	660	1.051	C* at 1.029 on 15.11.39	1.024, 1.024, 1.024, 1.022, 1.017, 1.013	29.4.40
10/39	27.11.39	550	1.046	(9 ozs. K.M.S. added per 100 gals. on 22.12.40) (C* at 1.028 on 5.1.40)	1.0215	26.4.40
11/39	30.11.39	550	1.050	(9 ozs. K.M.S. added per 100 gals. on 22.12.30) (C* at 1.020 on 1.1.40)	1.015	6.3.40
12/39	6.12.39	440	1.049	C* at 1.031 on 13.12.39	1.023	16.4.40
15/39	12.12.39	1100	1.046	C* at 1.029 on 19.12.39	1.020	18.4.40
16/39	15.12.39	1000	1.040	C* at 1.029 on 22.12.39	1.022	6.3.40
18/39	28.12.39	400	1.045	C* at gravities between 1.033–1.025 between 8.1.40 and 16.1.40	1.023	24.4.40
Vat 2	—	1080	1.028[b]	Vat filled with centrifuged cider on 14.11.39	1.020	4.6.40
Vat 3	—	1080	1.022[b]	Vat filled with centrifuged cider (with 6 ozs. K.M.S./100 gals.) on 1.1.40	1.015	4.6.40
Vat 4	—	1200	1.029[b]	Vat filled with centrifuged cider on 2.11.39	—	4.6.40
"Ebon" tank	—	2800	1.021[b]	Vat filled with centrifuged cider on 13.12.39	1.0205	7.3.40

[a] C* indicates centrifugation at gravity stated.

[b] Centrifuged cider.

When adequate clarification has not been accomplished, or when the cider contains large amounts of insoluble solids, it may become necessary to subject the cider either to preliminary filtration through a fairly porous filter medium or to centrifugal action before final filtration.

Sparkling Ciders. The filtration of sparkling ciders is accomplished in a closed system to avoid loss of the carbon dioxide charge. Pressure fittings are used to connect the fermenter, pump, filter, and receiving tank. The receiving tank is filled with carbon dioxide or air at a pressure equal to or slightly greater than that of the fermenter and the two tanks are then connected through a pressure equalizing pipe. The cider may then be pumped from the fermenter through the filter and into the receiving tank without loss of charge. See Fig. 86.

9. PRESERVATION

Bulk Storage. Cider is commonly held in bulk storage until needed for market. Uncharged cider may be held for considerable periods in tank storage if it has been properly racked, centrifuged, or otherwise treated to arrest fermentation. The common practice is to use large, lined concrete tanks or clean casks and maintain the storage temperature at from 45° to 50°F. It is desirable to provide the tank with an air trap to reduce danger of acetification. Sparkling ciders must be stored in pressure tanks to avoid loss of carbon dioxide. In all cases of bulk storage great care is taken to assure cleanliness so that infection of the cider with undesirable organisms is avoided. The ciders are inspected periodically and removed from storage for special processing if unwanted fermentation is taking place. The effects of centrifuging and treatment with sulfur dioxide in retarding fermentation during storage are shown in Table 45.

Metals in Cider Storage. The problem presented by the corrosive action of ciders to metals during preparation, fermentation, and storage has resulted in a number of studies on this subject. Aluminum, silver, and nickel have been found[785] to have little effect on the flavor and color of cider, whereas copper, lead, iron, zinc, and gunmetal dissolved and imparted slight to strong metallic flavors. Iron, copper, and zinc darkened the color. Tin did not alter the flavor but dissolved to a slight extent. Chromium–nickel steels (Cr 8–18% and Ni 11–18%) were highly resistant to corrosion. Austenitic cast irons, containing 5–8% chromium and 25 to 30% nickel, were less resistant.

[785] V. L. S. Charley, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1933,* 152.

The presence of 200 p.p.m. of sulfur dioxide in sweet ciders increased their corrosion of steels. Two samples of bronze (Cu 95% and Sn 5%, and Cu 96.5% and Sn 3.5%) were highly resistant to corrosion and caused no flavor change. In another study the metals considered were classified in the following order with respect to resistance to corrosion by cider; special steels A.R.C. 2702 and Uranus 10, pure aluminum (99.9%), Monel.[786] Aluminum metals were classified as follows: pure aluminum, 99.5% Al, Almasilium, and Al–Mn. Aluminum and its alloys were considered unsuitable for strongly sulfited juices because of the chemical reaction at liquid–air–metal contact. Nonsubmerged metal was corroded more than the submerged portion. In a later study these workers reported Inconel, a nickel alloy, inferior to the special steels A.R.C. 2702 and Uranus 10 but superior to Monel. Fermenting cider could be kept in Inconel containers without appreciable injury to the metal provided excessive amounts of sulfur dioxide had not been added.[787] Cement is extensively attacked by cider and this material should receive a protective coating before use.[788] Wood, in the form of casks and vats, is used extensively in preparing and storing cider. Because of flavors imparted by many woods only selected, properly seasoned woods may be used in the storage of cider. Oak is the most common wood for this purpose, though chestnut is also used. In a study of the suitability of various coniferous woods, British Columbian pine, Siberian red fir, Archangel white fir, New Zealand kauri pine, and Louisiana red cypress were found to affect adversely the flavors of ciders.[789]

Bottling. Cider is commonly marketed in bottles. If strict sanitary conditions have been maintained during preparation, no sterilization is necessary for bottled *dry ciders*. It is usually safer, however, to submit cider to a low temperature (145°F.) holding pasteurization in the bottle, or to subject it to sterile filtration before bottling. Flash pasteurization preliminary to sterile filtration is considered advisable by many workers to inactivate enzymes. Ciders containing residual

[786] G. Warcollier and J. Tavernier, *Congr. intern. tech. et chim. inds. agr., Compt.-rend. IV. Congr. Bruxelles, 3,* 448 (1935); *Chem. Abstracts, 30,* 7085.
[787] G. Warcollier and J. Tavernier, *Bull. assoc. chim., 59,* 464 (1942); *Chem. Zentr., 1943, I,* 2046; *Chem. Abstracts, 38,* 4374.
[788] G. Warcollier and J. Tavernier, *Congr. intern. tech. et chim. inds. agr., Compt.-rend. IV. Congr. Bruxelles, 3,* 442 (1935); *Chem. Abstracts, 30,* 6913.
[789] P. T. H. Pickford, *Ann. Rept. Agr. and Hort. Research Sta., Univ. Bristol, 1934,* 213 (1935).

sugars are more susceptible to disorders or continued fermentation, and sterilization in the bottle is therefore especially important in their preservation. Sweet ciders may, however, be kept in good condition in the bottle for 1 or 2 months by cold storage.[790]

Special filling and bottling equipment is required in handling *sparkling ciders* and in the preparation of carbonated cider. Sparkling ciders that have been sterilized by filtration may be filled aseptically into bottles using an isobarometric filler at high pressures. When the cider is to be pasteurized in the bottle a carbonation pressure of 30 pounds is the limit. *Carbonated ciders* may be prepared from dry ciders or from dry cider to which sugar or unfermented apple juice has been added by passing it through a carbonating machine and using an isobarometric filler.

Champagne type cider is prepared by blending selected dry ciders and adding sugar, or by blending dry and partially fermented ciders to the required sugar content. The blend is then inoculated with a champagne type yeast and filled into special, heavy glass bottles which are then corked and wired. The bottles are stored at reduced temperatures to permit slow fermentation which supplies the carbon dioxide required to give effervescence. After fermentation and a prolonged storage period, during which the bottles are turned and held in such a position that the sediment formed collects in the neck near the cork, the cider in the neck of the bottle is frozen and the cork and sediment removed. The bottle is then filled with cider, alcohol, or sugar solution to make a champagne that is either sweet or dry, before it is recorked and wired for market.

A rapid, bulk method for producing champagne cider, known as the *Charmat process*, consists in conducting the secondary fermentation of cider in a glass-lined, steel tank capable of being sealed and of withstanding high pressures. The sterilized cider, containing the sugar necessary for fermentation, is inoculated with a champagne type yeast and the secondary fermentation permitted to proceed in the closed vessel. During fermentation, which requires about 10 days, the pressure increases about 80 pounds per square inch. The product is then cooled and stored for a short period during which yeast and suspended material coagulate. The supernatant liquid is then filtered

[790] O. Grove, *ibid., 1930,* 195 (1931); *1931,* 171 (1932); *Chem. Abstracts, 27,* 4319.

under pressure through a special filter to produce a clear charged cider.

10. DISORDERS OF CIDER

Ciders, due to their low alcoholic content, are more subject to disorders than wines, and in common with wines, disorders are more likely to occur in ciders containing residual sugar than in those that are fermented completely dry. Disorders such as *cider sickness, oiliness,* and *ropiness* can only occur in ciders containing relatively high amounts of sugars. *Acetification, blackening,* and *greening* can develop in both fully and partly fermented ciders. Manufacturers who make a practice of storing dry or medium sweet ciders in bulk must keep a constant watch on their stocks, and at the first indication of spoilage apply curative treatments.

Acetification. The most common disorder of dry or partly fermented ciders is acetification, which may be caused by the action of one of several bacteria capable of converting alcohol into acetic acid. The bacteria can accomplish this change only in the presence of oxygen. To prevent exposure of cider to air it is necessary to wax the inside of wooden containers or varnish or paint the outside. A film of tasteless oil 0.5 inch deep on the surface will also check acetification in open containers.[791] Precautions during handling of the fruit and preparation of the juice to prevent infection are essential if continual difficulty from acetification is to be avoided. Periodic inspections of the condition of the cider indicate when acetification has commenced and such ciders are immediately sterilized by filtration or pasteurization and then placed in a sterile tank.

Cider Sickness (La Tourne). Cider sickness, known in France as la Tourne, is more common in warm sections and occurs only in ciders containing unfermented sugars. The disorder is caused by a side fermentation of residual sugars during the storage of partially fermented ciders, which results in the formation of aldehydes responsible for the characteristic flavor. One fermentation product of the disorder has been identified as mannitol.[792] There is an evolution of gas and the cider becomes turbid due to a combination of the aldehydes formed with tannins present in the cider. Washing the fruit used in preparing the cider with hot water at 60°C. will destroy the organism.[793] The

[791] R. W. Arengo-Jones, *Fruit Products J., 20,* 338, 353, 355 (1941).
[792] F. Tutin, *Biochem. J., 19,* 418 (1925).
[793] B. T. P. Barker, *J. Inst. Brewing, 19,* 58; *Chem. Abstracts, 7,* 2806 (1913).

disorder does not occur in ciders containing 0.5% or more of acid as malic, and its development is discouraged by steady fermentation and storage below 50°F.

When the sickness is well developed it is advisable to leave the cider alone for 9 to 12 months whereupon much of the flavor disappears and the cider will clear itself. If the acidity is low, fruit acids are added. Such cider may also be recovered by aerating with carbon dioxide gas to sweep out the aldehydes and then filtering. Incipient sickness is best treated by increasing the acidity and encouraging fermentation to dryness through added yeast, or by pasteurization. It is important to sterilize all equipment contaminated with sick cider to avoid infection of new stock.

Thickening, Oiliness, Ropiness. Infection with certain bacteria results in the formation of a viscous, oily cider which in its later stages is even ropy so that it will pour in threads like sirup. This condition, referred to as thickening, oiliness, and ropiness has been ascribed to the action of various anaerobic bacteria in the presence of residual sugar.[794,795] By using sufficient tart apples to bring the initial acidity up to 0.5% or more, there is no danger of ropiness setting in.[796] Treatment of oily cider is similar to that for sick cider except that it is necessary to discard the infected stock when the condition becomes advanced.

Green Cider. Ciders low in acidity, tannin, and nitrogen material, and high in mineral matter sometimes develop an olive-green color, which is accompanied by arresting of the fermentation and the deposition of starch. This condition has been ascribed to a combinaton of oxidized tannins with ferrous salts and the presence of nitrates is associated with the condition.[797] Acetylmethylcarbinol and 2,3-butanediol have been reported present in some ciders by several workers,[798,799] and these compounds have been associated with the development of *green cider*.[800] *Aerobacter aerogenes* and *Aerobacter*

[794] E. Kayser and A. Muntz, *Compt. rend., 152,* 1422 (1911); *Chem. Abstracts, 5,* 2690.
[795] O. Grove, *Ann. Rept. Agr. and Hort. Research Sta., Univ. Bristol, 1919,* 18; *Chem. Abstracts, 15,* 2957.
[796] O. Grove, *Ann. Rept. Agr. and Hort. Research Sta., Univ. Bristol, 1917,* 15.
[797] G. Warcollier, *Compt, rend., 158,* 973 (1914); *Chem. Abstracts, 8,* 2198.
[798] J. Pritzker and R. Jungkunz, *Mitt. Gebiete Lebensm. Hyg., 21,* 236 (1930); *Chem. Abstracts, 24,* 5421.
[799] D. W. Steuart, *Analyst, 69,* 307 (1944).
[800] G. Guittonneau, J. Tavernier, and M. Bejambes, *Compt. rend., 213,* 257 (1941); *Chem. Abstracts, 37,* 1796.

cloacae have been found in ciders containing these compounds. In the presence of nitrite ions, *Aspergillus* spp. produce a coloration identical with that of green sickness in cider. The slow fermentation obtained under industrial conditions favors growth of *Aspergillus* spp. and opportunity for development of undesirable acetylmethylcarbinol and 2,3-butanediol. Green colorations have also been observed in bottled ciders and ascribed to the presence of copper.[801]

Black Cider. Blackening of cider is caused by the presence of iron which combines with tannin to form a black or greenish black color. Its formation is usually accompanied by flavor deterioration. It is necessary to exercise extreme care, especially in areas which tend to produce juice high in iron, to avoid iron contamination during cider preparation. Adhering soil is washed from the fruit and the grater is frequently washed to avoid undue dissolving of iron. The formation of black color is not a problem in ciders above 0.5% in acidity. The condition can be reduced by use of tannin precipitating agents and by blending the stock with fresh juice and refermenting the entire stock, but prevention is considered simpler than attempting to correct the disorder. Blackening may also occur in bottled cider after opening to the air so that oxidation under conditions of low acidity can take place.

Break (Casse). Residual chlorine, remaining after bottle sterilization in the sterile filtration procedure, will produce a sediment in the bottled cider. To prevent this condition bottles should be rinsed sufficiently to assure that residual chlorine in the cider is below 200 p.p.m. Sedimentation in bottled cider, particularly when stored at high temperatures has been termed *break* or *casse*. Usually the cider takes on a deeper color. This difficulty has been attributed to the action of peroxidase on tannin. Development of break is not accompanied by loss of flavor and it is reported that it can be prevented by the addition of sulfur dioxide, after fermentation, to give a content of 80 p.p.m.[801]

C. Apple Wine

1. DEFINITION

Federal regulations, for purposes of taxation,[802] define apple wine as the product of the normal alcoholic fermentation of the juice

[801] R. W. Arengo-Jones, *Fruit Products J., 20,* 338, 353, 355 (1941).
[802] *Wine,* Bureau of Internal Revenue, U. S. Treasury Dept., *Reg. 7,* 1945, pp. 11–12.

of sound, ripe apples, with or without the addition of dry cane, beet, or dextrose sugar for the purpose of perfecting the product according to standards, but without the addition or abstraction of other substances, except as may occur in the usual cellar treatment of clarifying or aging. Provision is made for the use of apple brandy in the production of apple wine. This definition does not preclude the manufacture and sale, free of tax, of the farm product known as apple cider. The distinction between cider and apple wine is usually made on the basis of alcohol content. Natural apple juices, when fully fermented, rarely contain more than 7% alcohol and usually contain much less since about 2% sugar is required in the juice for each 1% of alcohol produced. Fermented apple products containing less than 8% alcohol are usually considered as cider, although uniform standards on this point have not been established.

2. PRODUCTION

Apple wine is produced extensively only in the United States, where apples are exceeded only by grapes and raisins in the quantities used for wine. In the fiscal year 1945 almost 21.5 million pounds of apples and over 1.75 million gallons of apple juice, including concentrates, were used in the production of wine.[803]

3. CLASSIFICATIONS OF APPLE WINE

Alcoholic Content. For purposes of taxation the United States Government has divided wines into three classes on the basis of alcohol content.[804] The first class, containing not over 14% alcohol, by volume, may be produced by natural fermentation in the presence of adequate sugar. Wines containing more than 14%, but not more than 21% alcohol, by volume, constitute a second class, while wines containing more than 21% alcohol, but not more than 24% alcohol, by volume, comprise the third class. Wines containing more than 24% alcohol, by volume, are classed as distilled spirits. In preparing the second and third classes it is necessary to fortify the naturally fermented wine with alcohol, as most strains of wine yeast are incapable of producing a wine of higher than 14% alcohol content.

Flavor. Apple wines are further classified, on the basis of their sugar content, as sweet, semisweet, and dry (low in sugar). Effervescent apple wines, in which the carbon dioxide charge is produced

[803] *Ann. Rept. Comm. Int. Revenue,* U. S. Treasury Dept., 1945, pp. 184–5.
[804] *Wine,* Bureau of Internal Revenue, U. S. Treasury Dept., *Reg. 7,* 1945, p. 3.

either by natural fermentation or by artificial carbonation, constitute additional types which are subject to special tax rates.

4. APPLE WINE MANUFACTURE

Apples Used. Apples used in preparing wines in the United States consist of dessert and culinary varieties commercially available. Culls, windfalls, and second-grade fruit from the fresh fruit industry supply the bulk of this fruit and the wine maker must select and blend the varieties available to him to obtain a product of the desired flavor. Data presented in Chapter XII on the qualities of the different varieties for juice purposes serve as a guide in making such blends, but special considerations are required in blending for wine purposes since the sugar–acid ratio desired for the fermented product differs from that preferred in fresh juice.

Juice Preparation. The procedures used in preparing juice for wine manufacture are similar to those described in Chapter XII for the production of apple juice. The processes of maceration and keeving, outlined for cider, are not practiced in preparing apple wine.

Fermentation. Methods presented for cider for conducting the fermentation of apple juice are used in preparing wine, and the same considerations of methods and their effect on final quality apply.

Amelioration. A considerably higher alcohol content is desired in the manufacture of apple wine than it is possible to obtain from pure apple juice. Several procedures are used to increase the alcohol content to the desired point. To produce a naturally fermented wine sufficient dry sugar may be added to the juice to yield the alcohol content desired. Another method consists in ameliorating the juice with a sugar sirup. Federal regulations stipulate that water added in amelioration must not dilute the juice below an acid content of 0.50%, and in no case should the water increase the volume more than 35%. When either dry sugar or sugar sirup is added the product may not contain more than 13% alcohol after complete fermentation.[805] A juice which contains 20.24% sugar will, with good commercial fermentation, yield 13% alcohol by volume. In calculating the amount of sugar necessary to give the desired alcohol content, soluble matter in the juice which is not sugar and does not produce alcohol must be considered. This nonsugar content produces about 2° Brix (Balling)

[805] *Wine,* Bureau of Internal Revenue, U. S. Treasury Dept., *Reg. 7,* 1945, pp. 76–78.

which is subtracted from the Brix reading to obtain the Brix due to sugar. Either sucrose or dextrose may be used in ameliorating apple juice. Studies on the relative merits of these two sugars in ameliorating apple musts indicate that dextrose is utilized somewhat faster during fermentation and results in a wine with a slightly lower volatile acid content, but no differences were noted in flavor, aroma, or body that could be attributed to the use of these sugars.[806]

Fortification. Apple wines of higher alcohol content than 13% are prepared by adding alcohol in the form of apple brandy. The wine may be partially fermented to the desired sugar content before fortification or unfermented juice itself may be fortified. The sweetness of apple wine may be controlled either by halting the fermentation when the residual sugars are at the desired point or by adding sugar after fermentation, but sugar may not be added after fortification under existing Federal regulations.

Freezing. Another method for increasing the alcohol content of cider and wine is by freezing. Water may be removed from the fermented product by slowly freezing in a cask until the desired concentration of alcohol and solids results or by any of the methods outlined in Chapter XII for concentrating apple juice. The freezing process concentrates acids and dissolved solids as well as alcohol, and therefore tends to give a very tart wine. Freezing concentration of wine is not practiced on a commercial scale because of the greater efficiency of modern distillation equipment.

Filtration. Apple wines are marketed as clear products and, therefore, require filtration. Clarification prior to filtration is usually not necessary because of the clarification which takes place during fermentation, and practical filtration speeds are often obtained by the use of filter aids. The filtration procedures outlined in Chapter XII for apple juice are used in preparing apple wine.

Aging. Apple wine is aged in completely filled tanks or casks, preferably of oak. Two to three months are usually sufficient to dispel the yeasty flavor and odor to produce a mellow wine of pleasing flavor and aroma. Sherry-like wine can be made by baking apple wines, fortified to about 20% alcohol, at from 120° to 140° F. for 3 to 6 weeks and aging in wood.

Pasteurization and Bottling. Noncarbonated wines may be pas-

[806] H. E. Goresline, E. A. Beavens, and A. L. Curl, *Fruit Products J., 20,* 10 (1940).

teurized by either the flash or holding methods described for apple juice (Chapter XII). Flash-pasteurization temperatures of from 145° to 150° F. are adequate, or the sealed bottles may be held at about 150° F. for 30 minutes. The pasteurized and bottled wine is cooled in water. Wines carbonated at low pressures may be pasteurized in the bottle by the holding method.

D. Apple Brandy

1. PRODUCTION

Apple brandy, also known in the United States as *applejack,* is the product obtained by the distillation of fermented apples or residues or products of apples. When properly prepared from selected ciders it is a highly prized beverage. France, the principal apple brandy producing country in Europe, produces the equivalent of about 7 million gallons of 100% alcohol annually from this source.[807] A considerable portion of this is consumed as brandy, which is known as Calvados. In the United States apple brandy is produced for beverage use and for use in the fortification of apple wines. About 12.5 million gallons of apple juice were used in the production of nearly 1.4 million tax gallons[808] of brandy in the United States during the fiscal year 1945.[809]

2. BRANDY MANUFACTURE

Juice Preparation and Fermentation. Methods outlined in Chapter XII for the preparation of apple juice are commonly employed in preparing juice for brandy, and fermentation processes discussed for cider apply in the fermentation of juice for brandy. The same care in the selection of fruit and in the preparation and fermentation is used in the production of high quality beverage brandies as is employed to produce a good cider. Rapid fermentation of apple juice has been found to yield brandies always much lower in ester content and some-

[807] V. L. S. Charley and T. H. J. Harrison, *Imp. Bur. Hort. and Plantation Crops., East Malling, Kent, Tech. Commun., No. 11,* 77 (1939).

[808] For spirits of 100 proof or over, a tax gallon is equivalent to one U. S. gallon of an alcoholic mixture containing 50% alcohol by volume (proof gallon). For spirits of less than 100 proof, the tax gallon is a standard U. S. gallon.

[809] *Ann. Rept. Comm. Int. Revenue,* U. S. Treasury Dept., Fiscal Year 1945, pp. 168–169, 184, 188.

times also lower in acid than normally fermented juices.[810] A disorder of cider that has given difficulty in the distillation process is the formation of acrolein by bacterial action on glycerol previously formed during fermentation.[811] Apple brandy obtained by fermentation of pulped apples has been found to be inferior in aroma and flavor to that obtained by the fermentation of apple juice.[812]

Distillation is in effect a purification process whereby nonvolatile materials are removed and some control may be realized in segregating volatile constituents. It is therefore possible to use fruit and cider of lower quality for brandy than is possible in the preparation of apple juice or cider, particularly if the brandy is highly rectified for use in fortifying wines. Brandy is frequently produced from apple waste of other processing plants, including water extracts of once-pressed pomace. The advantages in preparing brandy from peel and core material containing excessive quantities of spray residue metals, for example, are quite apparent when one considers that these metals will not contaminate the final product.

Distillation. Brandies may be classified into two general types on the basis of the degree of distillation or rectification to which they have been submitted. *Beverage brandies* are usually rectified to less than 65% alcohol (130° proof distillation). The lower the proof distillation, the more brandy character retained. *High proof brandy,* rectified to as high as 95% alcohol (190° proof), is commonly used in fortifying wines. High proof distillation results in a pure, neutral flavored product which has very little brandy character, and ciders of inferior beverage quality may be used for this purpose since many objectionable flavors may be removed in the distillation process.

Two general types of stills are used in preparing brandy. The *pot still,* consisting of a vat for heating the juice and a simple condenser for recovering the distillate, produces a brandy rich in apple flavor but requires the use of high quality ciders to produce a good product. Two distillations are usually made, the first producing a product of about 30% alcohol which is then redistilled to yield brandy

[810] G. Warcollier and A. Le Moal, *Ann. fals. et fraudes, 25,* 337 (1932); *Chem. Abstracts, 26,* 4908.

[811] G. Warcollier and A. Le Moal, *Compt. rend., 194,* 1384 (1932); Chem. *Abstracts, 26,* 3613. G. Warcollier, A. Le Moal, and J. Tavernier, *Compt. rend., 198,* 1546 (1934); *Chem. Abstracts, 28,* 5593.

[812] W. Zimmerman and K. Wöger, *Z. Spiritusind., 60,* 161 (1937); *Chem. Abstracts, 32,* 2682.

of from 55 to 67% alcohol. Practical limitations of this type still prevent the production of high proof, fortifying brandy.

Beverage brandies are preferably aged in oak casks until suitably mellowed and then filtered before bottling for market.

The initial boiling components, known as *heads,* contain as the principal objectionable substances acetaldehyde and, if present, sulfur dioxide. The heads are usually discarded from the second distillation. The last vapors evolved during the distillation, termed *tails,* contain constituents of high boiling point, principally higher alcohols, which are also discarded. Federal regulations define "heads and tails" as the distillates containing 0.5% or more of aldehydes or 1% or more of fusel oil.[813]

The *continuous still,* consisting of a tall column supplied with perforated plates and baffles, is essentially a series of pot stills in which the distillate in one chamber is heated by the vapors from the one immediately below. Continuous stills are highly efficient in rectifying alcohol and, when supplied with sufficient chambers, may be used to produce brandies containing up to 95% alcohol in a single passage. Heads and tails are removed from continuous stills at appropriate levels in the column. The alcohol content progressively increases and the boiling point progressively decreases from the bottom to the top of the column so the highest proof alcohol is removed from the top chamber while the low-alcohol slop, together with condensed steam from the steam generator, is removed from the bottom of the column. Fermented stock is added continuously at an appropriate level in the column.

Alcohol Yields. Several workers have investigated the yield of alcohol possible to obtain from apples by fermentation and distillation. Yields of 10.7 to 12.6 gallons of 95% alcohol per ton of apples have been reported.[814,815] In distilleries using apples, alcohol yields have been reported as usually equivalent to less than 80% of the sugar in the freshly pulped fruit, as determined by copper reduction. The deficit is not accounted for by the reducing substances in the exhausted pulp and vinasse. A well-conducted and controlled distilla-

[813] *Production of Brandy,* Bureau of Internal Revenue, *Reg. 5,* U. S. Treasury Dept., 1940, p. 24.

[814] G. Ray, *Compt. rend. acad. agr. France, 9,* 929 (1923); *Chem. Abstracts, 18,* 1545.

[815] M. L. Levy, *Bull. assoc. chim. sucr. dist., 46,* 148 (1929); *Chem. Abstracts, 24,* 1699.

tion showed 1 to 3% of the original reducing substances in the exhausted pulp and 87 to 89% in the juice before fermentation, giving an unaccounted for loss of about 10% for the extraction process. Analysis of the fermented juice indicated a further loss of 6 to 8% unaccounted for as alcohol on the basis of 7.3 gallons of absolute alco-

TABLE 46. ESTIMATED YIELDS OF ALCOHOL FROM VARIOUS FRUITS[818]

Fruit	Approximate sugar content in flesh or in juice,[a] %	Estimated yield of alcohol, gallons per ton[b]	Value of alcohol from 1 ton of fruit, alcohol at[c]	
			22¢ a gallon	30¢ a gallon
1. Apples	12	14	3.08	4.20
2. Apricots, fresh	11	12	2.64	3.60
3. Figs, dry	45	58	12.76	17.40
4. Grapes, fresh	20	25	5.50	7.50
5. Grapefruit, fresh	6.5	4	0.88	12.00
6. Muskmelon and cantaloupes, fresh	5.5	6.5	1.43	1.95
7. Oranges	10.0	7.0	1.54	2.10
8 Peaches, fresh Cling	8.0	8.0	1.76	2.40
9. Peaches, dry	60	75	16.50	22.50
10. Pears, fresh	9	11.5	2.53	3.45
11. Prunes, dry	50	51	11.22	15.30
12. Plums, fresh	8.5	11	2.32	3.30
13. Raisins	60	65	14.30	19.50
14. Watermelon	6.0	6.5	1.43	1.95

[a] In calculating yields of alcohol per ton of fruit allowance has been made for pits, seeds, and skins.

[b] In estimating probable yields, it was assumed that nine tenths of available sugar is converted to alcohol.

[c] Cost of producing 95% alcohol is about 12¢ a gallon if a liquid waste such as pineapple juice is used; a large amount of this being for fuel oil burned to produce steam for distillation. It costs probably $3.00 a ton or more to pick and deliver fresh fruits to factory.

hol per 100 pounds of hexose sugars, or as unfermented reducing substances. Yields equivalent to 96% of the reducing substances in the pulp were obtained in experimental fermentations but these yields were not realized in large-scale manufacture.[816] The best method for reducing losses is rapid fermentation as soon as possible after pulping, and the use of selected yeast. Studies have been made on the

[816] J. Vidal and P. Vidal, *Bull. assoc. chim. sucr. dist., 47,* 393 (1930); *Chem. Abstracts, 25,* 4654.

possibility of utilizing the equipment in sugar beet distilleries for the production of alcohol from apples.[817]

E. Industrial Alcohol from Apples

The possibility of converting surplus and waste fruits, including apples, into alcohol for other than food uses has been advocated as a means of disposing of such fruit in the interest of maintaining the fresh market at suitable price levels. The use of such alcohol in motor fuels and other industrial products would offer a market outlet for all surplus fruits available. Table 46 presents data on the estimated yields and value of alcohol produced from a number of fruits. Cost figures are based on the 1935 price level when the approximate price for ordinary industrial alcohol was 30 cents per gallon, f.o.b. distillery, and the estimated value of alcohol for motor fuel was 22 cents per gallon. As may be seen from the table the value of the alcohol obtainable from one ton of apples, after deduction of pressing, fermentation, and distillation costs, would leave very little if any margin for the value of the fruit used. In addition, it is not economical to build expensive alcohol plants which depend on sporadic supplies of cull or surplus apples for operation. Thus, it would be necessary to subsidize heavily such apple utilization or tax the consumer heavily in order for apples to compete with other sources of alcohol or for alcohol itself to compete with petroleum as a fuel.

F. Cider Vinegar

1. PRODUCTION

Vinegar is a condiment made from various carbohydrate materials by alcoholic and subsequent acetous fermentation. It is used extensively in the manufacture of various food products such as pickles and sauces, in cooking, and for table use. Among the materials used in its manufacture are fruits, tubers, cereal grains, and sugar products such as molasses and refiners' sirup. Only on the North American continent is vinegar produced to any extent from apples. According to

[817] E. Saillard, *Mon. sci., 6,* 25 (1916); *Chem. Abstracts, 10,* 1075. E. Saillard, *Compt. rend. acad. agr. France, 2,* 676 (1917); *Chem. Abstracts, 11,* 2711. R. Pique, *Chimie & industrie, Spec. No.,* 648 (May, 1924); *Chem. Abstracts, 18,* 3249.

[818] From W. V. Cruess, *Fruit Products J., 15,* 296 (1936).

the United States Census Bureau[819] over 100 million gallons of vinegar, valued in excess of 11 million dollars, were produced in the United States in 1939. Statistics do not segregate vinegars according to the materials from which they are prepared but a considerable part of this production is cider vinegar.

2. DEFINITIONS

Vinegars are classified on the basis of the materials from which they are made and the method used in their preparation, and government regulations prescribe certain standards which must be met in their preparation as well as necessary labeling so that consumers may distinguish the different products.

Vinegar, Cider Vinegar, Apple Vinegar. In the United States the unqualified term, *vinegar,* implies that the product is prepared from fresh, whole apples by the direct acetous fermentation of cider. The distinguishing terms, *cider vinegar* and *apple vinegar,* are also applied to this product. When vinegar is prepared from dried apple products it is identified as *vinegar made from evaporated apple products.*

Vinegar from Other Products. Vinegars prepared from materials other than apples are identified by descriptive terms. *Wine* or *grape vinegar* is prepared from fresh grapes, and terms such as *sugar, glucose,* or *corn sirup* are used to identify vinegar made from these products. Vinegar prepared from a cereal that has been saccharified by means of barley malt without a distillation step in the process is identified as a *malt vinegar.*

Distilled Vinegar. Vinegar prepared by the acetous fermentation of an alcoholic solution that has previously been rectified by distillation is known as a *distilled, grain,* or *spirit vinegar.* Whereas plain vinegars contain most of the soluble extractives of the material from which they are prepared, distilled vinegars contain only volatile extractives and are therefore generally considered to be harsher and less flavorful.

3. CIDER VINEGAR MANUFACTURE

Preparation of Cider. The first step in the manufacture of vinegar from fresh apples is the preparation of cider, and methods described for pressing the fruit (page 323) and for the fermentation of dry (hard) cider (page 387) are commonly employed. When apple

[819] *Western Canner and Packer, Yearbook Number, 38,* 252 (1946).

chops or dried skins and cores are used these are leached with hot water to extract the soluble solids. By using a continuous leaching system an extract of 11 to 12% soluble solids may be obtained, or the extract may be concentrated to this point in order to obtain an extract equivalent to apple juice in solids content. Boiling the dried fruit with water results in the extraction of excessive quantities of pectic materials which complicate clarification of the final vinegar. The soaked fruit may be pressed but this requires extra handling and the pressed juice contains considerable suspended solids that must be removed in later processing. When concentrated apple juice is used sufficient water is added to restore the original volume.

Natural (spontaneous) fermentation is usually employed and may be conducted at somewhat higher temperatures than are commonly used in cider manufacture, in order to obtain a rapid conversion of the sugars into alcohol. It is desirable that alcoholic fermentation be complete before acetification begins, as acetic acid interferes with alcoholic fermentation.[820] After fermentation the suspended solids are allowed to settle and the surface is skimmed. A thin layer of oil may be spread over the cider to prevent the growth of foreign bacteria when it is to be stored for a period in open tanks. Before acetification the cider is usually strained or filtered to remove remaining suspended material which may introduce difficulty during the acetification process. Procedures followed in the filtration of apple juice (Chapter XII) are used in filtration, although clarification treatments are not usually required because of the natural clarification that takes place during alcoholic fermentation and settling. Filter aids are usually employed to speed filtration.

Acetification (Generation). Acetification of cider is accomplished by means of different types of acetic bacteria. The main chemical change involved in the process may be represented by the following equation:

$$\underset{\text{(alcohol)}}{C_2H_5OH} + \underset{\text{(oxygen)}}{O_2} \xrightarrow{\textit{Acetobacter}} \underset{\text{(acetic acid)}}{C_2H_4O_2} + \underset{\text{(water)}}{H_2O}$$

The fact that free oxygen is required to complete this reaction emphasizes the importance of preventing the introduction of air during the preparation of ciders and wine to avoid acetification of these products.

[820] P. Hallack, *Deut. Essigind., 25,* 93 (1921); *Chimie & industrie, 7,* 352 (1922); *Chem. Abstracts, 16,* 1481.

TABLE 47. Composition of Juices, Finished Vinegar, and Intermediary Products[821]

Results Expressed in Grams per 100 cc. Except Where Otherwise Noted

	Composite apple juice		Juice, fermented, stored		Vinegar stock, blend of 1st and 2nd pressings	Vinegar, filtered stock	Cleared vinegar	Vinegar, stored, filtered stock
	1st pressing	2nd pressing	1st pressing	2nd pressing				
Date sampled	10/24/13	10/27/13	11/23/14	11/23/14	12/7/14	1/30/15	3/1/15	10/3/15
Specific gravity $\frac{15.6°C.}{15.0°C.}$	1.0592	1.0334	0.99820	1.0053	0.99849	1.0150	1.0159	1.0159
Alcohol, % by volume	0.07	2.25	7.40	5.45	7.00	0.18	0.17	0.04
Solids, by weight	14.98	8.74	1.58	2.13	1.51	1.34	1.43	1.32
Sugars as invert sugar								
Before inversion	11.82	5.45	—	—	—	—	—	0.45
After inversion	12.17	5.56	—	—	—	—	—	—
After evaporation	—	—	0.03	0.09	0.03	0.07	0.08	0.12
Sucrose, by copper	0.24	0.10	—	—	—	—	—	—
Nonsugar solids	2.82	3.19	1.55	2.04	1.48	1.27	1.35	1.20
Volatile reducing substances, as invert sugar	—	—	None	None	None	0.027	0.28	0.33
Acids as malic, as acetic[a]	0.59	1.03	0.83	1.47	0.78	6.45[b]	6.47[b]	6.47[b]
Volatile acids as acetic	0.02	0.26	0.47	1.02	0.49	6.37	6.41	6.44
Fixed acids as malic	0.57	0.74	0.31	0.34	0.24	0.07	0.07	0.03
Ash	0.33	0.37	0.33	0.39	0.33	0.32	0.32	0.30
Alkalinity of water-soluble ash[c]	34.0	37.0	35.4	38.0	35.0	31.6	33.2	34.4
Total P_2O_5, mg./100 cc.	27.4	32.7	26.5	31.7	25.8	22.0	23.6	23.7
Glycerin	—	—	0.26	0.25	0.25	0.25	0.25	0.24
Pentosans	—	—	0.028	0.193	0.041	0.073	0.076	0.083
Proteins (N × 6.25)	—	—	0.046	0.074	0.044	0.035	0.035	0.033

[a] On all juices and stocks determined indirectly, in all vinegars determined directly.

[b] Determined in distillate.

[c] Cubic centimeters of 0.1 *N* acid per 100 cc.

Besides the conversion of alcohol into acetic acid a number of side reactions take place during this fermentation which alter the final composition of the vinegar. Malic acid is almost completely oxidized into lactic acid, and glycerin, among other by-products, appears in the final product in considerable amounts. Table 47 presents data on the composition of apple juice, finished vinegar, and intermediary products. Rotating generators were used in the final fermentation.

Two conditions must be met in the acetification of cider. The cider must contain viable *Acetobacter* and oxygen must be present. The efficiency and speed of conversion depend largely on the efficiency of aeration during the fermentation. In small farm operations the acetification is accomplished by placing the cider in a barrel supplied with ventilating holes in the head and inoculating with freshly prepared vinegar or with *mother of vinegar* which forms during the acetification process. Conversion of the alcohol to acetic acid by this procedure requires several months because of the inefficiency of aeration.

Vinegar is produced commercially by means of an apparatus known as a *generator* which, through efficient aeration of the inoculated cider, promotes rapid conversion of the alcohol to acetic acid. The literature contains a comprehensive review of patents pertaining to the generator process for making vinegar.[821] The most common type of generator consists of a vertical tank fitted with a false bottom and filled with beechwood shavings, corn cobs, pumice stone, rattan, coke, or other suitable material. Air holes are provided below the false bottom and in the head and a distributing arrangement is supplied for feeding the fermented cider stock over the surface of the tank. The size of the generator varies but practice has shown that the height of the tank should be several times greater than the diameter and that diameters in excess of 18 to 20 feet result in less efficient aeration.

Before a generator is placed in use it is necessary to inoculate the packing material with active acetic bacteria. The most common method for inoculating generators is by introducing warm cider vinegar until it flows from the bottom and a good draft has been started. A mixture of equal parts of cider stock and vinegar is then passed

[821] From B. G. Hartman and L. M. Tolman, *Ind. Eng. Chem.*, *9*, 759 (1917).
[822] A. W. Bitting, *Fruit Products J.*, *8* (7), 25; *8* (8), 16; *8* (9), 13; *8* (10), 18; *8* (11), 16; *8* (12), 18; *9* (1), 19; *9* (2), 49; *9* (3), 86 (1929.

through the generator whereby heat generated in the acetification reaction maintains the draft. Control of the acetification process is accomplished by regulating the proportion of cider stock to vinegar, the rate of flow of this mixture, and the temperature. Each generator responds differently and efficient operation depends to a large extent on the skill and ability of the operator.

Complete conversion of cider stock to vinegar in one run through the generator is not practical because of the slow rate of flow necessary and the danger of excessive slime formation on the packing material which accompanies the slow rate of flow. Several systems are used for operating the generator. The generator may be used to convert about one half of the alcohol into acetic acid after which the product is allowed to complete acetification in a vat; two or more generators may be operated in series so that each accomplishes a part of the process; or the generator may be supplied with an equal mixture of cider stock and vinegar.

Beside the conventional vertical generator, rotating generators have been developed for the acetification process.[823] The revolving generators consist of a rectangular covered tank containing fermented stock, in which a slatted drum containing beechwood shavings revolves slowly with about one third of its diameter immersed in the stock. Four to six weeks are required to complete the acetification and the product is very low in total solids but high in acid. Practically all of the malic acid is converted to lactic acid and greater yields of acid (1 part of alcohol will yield 1% acid) are realized. Although the process requires less attention than vertical generators it requires more time.

To obtain effective control of the generation process it is necessary to know the alcohol and acetic acid contents of the stock being used. Alcohol may be determined by distilling the neutralized stock and determining the specific gravity of the distillate. Plant operators more frequently depend on the use of the *ebulliometer,* an instrument for measuring the boiling point of the alcoholic mixture as compared with distilled water. Acid is determined by titration with a standard alkali in the presence of phenolphthalein indicator.

The acid content of vinegar is commonly expressed in terms of *grains,* each gram of acid in 100 cubic centimeters of vinegar being equal to 10 grains. Thus, a 40 grain vinegar contains 4 grams of acetic

[823] B. G. Hartman and L. M. Tolman, *Ind. Eng. Chem., 9,* 759 (1917).

acid per 100 cubic centimeters. The acid content obtainable from a given cider depends on its alcohol content. On the basis of chemical equivalents, 1 part of alcohol should yield 1.3 parts of acetic acid, by weight. Actual yields are never this high, however, and the production of from 0.8 to 1.0 part of actic acid for each part of alcohol is obtained commercially. A small amount of alcohol, 0.25 to 0.50%, remains in the finished vinegar. The efficiency of the generation may be expressed as the ratio of the acetic acid produced to the acetic acid theoretically expected from alcohol consumed. Vinegars of low acid content are blended with stronger vinegars in order to standardize the product.

Distilled (White) Cider Vinegar. A process has been suggested for converting conventional cider vinegar to a white vinegar by distillation. To avoid a scorched flavor the still is operated at about 24 inches vacuum and the still is constructed of special stainless steel to resist corrosion. Although it is not economically feasible to increase the strength of a weak vinegar by distillation, a white vinegar with exactly the flavor of the undistilled product may be produced with an acid recovery of 98% by volume, without loss of acid strength.[824] Such a vinegar would not conform to the definition for distilled vinegar previously given (page 411) since the distillation is conducted after acetification. It is possible to concentrate vinegar by freezing, whereby all of the dissolved solids are retained in the concentrated product but freezing concentration is not practiced commercially.

Aging, Filtration, and Bottling. After acetification vinegar is aged for about six months to develop flavor and assist in clarification. Filtration is an important step in preparing the product for marketing as it must not only be clear but remain clear during storage. Among the agents employed to clarify vinegar are gelatin–tannin, gelatin, isinglass, casein, and bentonite. The principles outlined under clarification of apple juice (Chapter XII) apply but some modifications in procedure are used. The problem of clouding and preciptation during storage noted under apple juice (page 364) also occurs in vinegar and appears related to the method of clarification employed. Special clarification methods have been proposed which appear capable of producing a clear vinegar that remains clear in storage.[825] Clouding need not be evidence of bacterial activity. Filtration is accomplished in the manner described for apple juice and a filter aid is usually em-

[824] R. W. Arengo-Jones, *Fruit Products J., 20,* (12), 372 (1941).
[825] L. G. Saywell, *Ind. Eng. Chem., 26,* 379 (1934).

ployed. Vinegar is bottled and pasteurized by heating to 150° F. and filling hot or by holding pasteurization after bottling.

Disorders of Vinegars. A number of disorders may occur in vinegar, particularly during the period when it is aged or held in bulk. Unless precautions are taken to maintain sanitary conditions, vinegar flies (*Drosophila* spp.) will infest the plant. All vessels used for vinegar are protected by screens, and vinegar is not allowed to stand in open vats because of the danger of infestation. Infestation of the vinegar with vinegar eels (*Anguilluls aceti*), an organism requiring oxygen for growth, and vinegar mites or lice, frequently results when unsanitary conditions prevail in the vinegar plant. The presence of excess iron in the vinegar results in discoloration varying from a grey cast to an inky blackness and precautions are taken to avoid contamination of the product with iron during manufacture.

G. Miscellaneous Fermentation Products

Calcium Gluconate. The production of calcium gluconate from apple juice media by fermentation has been investigated as a possible outlet for surplus apples.[826] Best yields of gluconic acid were obtained with *P. citrinum*. Calculated on the basis of glucose used, good yields of gluconic acid resulted, although utilization of total sugars was low because of the inability of this organism to utilize fructose.

Yeast. The possibility of utilizing surplus apples in the manufacture of yeast for food and feed purposes has received study. *Torulopsis utilis*, one of the yeasts suitable for food, has been grown in apple juice media using ammonium sulfate and ammonium hydroxide as source of nitrogen. The process depends on the utilization of sugars by the yeast to produce multiplication of yeast rather than alcohol and the fermentation process is carried out under conditions of active aeration. A yield of 42 grams of dry yeast per 100 grams of sugar has been obtained from apple juice in laboratory fermenters. The yeast had a protein content of 58% and an average vitamin content, expressed as parts per million on a dry basis, as follows: thiamin 14, riboflavin 38, nicotinic acid 375, and pantothenic acid 120. Yields and vitamin values correspond to those obtained in yeast obtained from other sources.[827] Greatly increased yeast cell concentrations were found possible by improvement of aeration.[828]

[826] C. Frost, J. L. St. John, and H. W. Gerritz, *Ind. Eng. Chem., 28*, 75 (1936).
[827] J. J. Stubbs, W. M. Noble, and J. C. Lewis, *Food Inds., 16*, 694, 751 (1944).
[828] I. C. Feustel and H. Humfeld, *J. Bact., 52*, 229 (1946).

CHAPTER XIV

JELLY, BUTTER, AND OTHER APPLE CONFECTIONS

A. History and Production

The preparation of fruit jellies, jams, and butters developed as a household art whereby fruits were preserved with sugar or spices in the form of gelatinous, viscous, or semisolid fruit confections for use as spreads and in baking. The consistency of these products depends wholly or in part on the formation of a pectin gel in the presence of the proper concentrations of sugars and acids. The housewife, in preparing preserves, is usually unaware of the pectin chemistry involved in obtaining the desired consistency but she understands that apples were very useful in attaining suitable products. Apples, with their rich content of jelly type pectin, were probably among the first fruits used in preparing jellies, and it was soon learned that certain fruits such as raspberries and strawberries, which are low in pectin, would not make satisfactory jellies unless apples were used in their preparation.

Advances in the chemistry of pectin and its gels have made it possible to control the consistency of these products under commercial methods of production and have stimulated the development of an important preserving industry, particularly in the United States and Great Britain. This industry produced an all-time high of about 850 million pounds of jellies, jams, preserves, marmalades, and fruit butters in the United States in 1944.[829] Statistics do not differentiate between these products on the basis of the fruit from which they are prepared, but apples are one of the more important fruits used. Over 80 million pounds of apple butter, representing nearly 13% of the total United States production of preserves, were manufactured in 1943.[830] In addition to its direct use in preserve manufacture, apple

[829] *Western Canner and Packer, Sta. Rev. and Yearbook No., 38,* 238 (Apr. 25, 1946).
[830] *Ibid., 36,* 219 (Apr. 25, 1944).

pectin is used in the manufacture of these products from fruits naturally deficient in pectin.

Limited quantities of apples are used in the preparation of candied and glacéd fruits and in fruit candies. Their relatively high content of pectin makes them useful in the preparation of gelatinous types of candies but their mild flavor and soft texture after cooking make them relatively unimportant among fruits in the preparation of candied and glacéd fruit. Data on the quantities of apples used in such products are not available.

B. Definitions and Standards of Identity

The commercial manufacture of fruit jams, jellies, and butters in the United States is subject to regulation by the Food and Drug Administration of the Federal Security Agency under the Federal Food, Drug, and Cosmetic Act of 1938. Under this act definitions and standards of identity for these products have been promulgated[831] and such products are deemed to be misbranded unless they conform to such definitions and standards and meet prescribed label requirements. Standards for grades of apple jelly and apple butter have also been established by the Production and Marketing Administration, United States Department of Agriculture[832,833] for convenience in wholesale transactions. A summary of these regulations, as they apply to apple products, is presented together with some further classifications observed by the trade.

1. APPLE JELLY

Fruit jellies are differentiated from other fruit preserves by the fact that they contain little or no insoluble solids and are therefore clear and transparent. They are the gelled foods made from a mixture of not less than 45 parts by weight of fruit juice ingredient to each 55 parts by weight of sugar ingredient. The mixture is concentrated by heat to such a point that the soluble solids content of the finished jelly is not less than 65%. Fruit juice ingredients consist of the

[831] *Definitions and Standards for Food,* Federal Security Agency, Food and Drug Administration, Service and Regulatory Announcements, Food, Drug, and Cosmetics *No. 2,* July 1944.

[832] *Federal Register,* F. R. Doc. 47-7569, 12, No. 158, 5488, 5489 (Aug. 13, 1947).

[833] *Tentative United States Standards for Grades of Apple Butter,* Prod. and Marketing Admin., U. S. D. A., Oct. 1, 1945.

filtered or strained liquid extract prepared with or without the application of heat and with or without the addition of water, from one of a number of specified, mature, properly prepared fruits which may be fresh, canned, or frozen. Apples and crabapples are among the optional fruits that may be used, and when either is used alone the product is labeled *Apple Jelly* or *Crabapple Jelly* to indicate the fruit source. Two or more fruit juice ingredients may be mixed, provided no one constitutes less than one fifth of the total fruit juice ingredients present, whereupon the product may be labeled *Mixed Fruit Jelly* or the names of the fruits used may precede the word jelly in the order of their dominance.

The proper proportion of fruit juice ingredient, whether concentrated, unconcentrated, or diluted, is calculated on the basis of the soluble solids content of the ingredient compared with that of the fruit from which it was prepared. Optional sugar ingredients that may be used are sucrose, invert sugar sirup, corn sirup, honey, or specified combinations of these with or without dextrose. The weight of these ingredients to be used is based on their solids content and when corn sirup or honey is used their presence must be declared on the label. Pectin, and certain specified organic acids, may be added to the jelly to compensate for deficiencies of these substances in the fruit juice used and sodium citrate and sodium potassium tartrate may be added in limited amounts to control gel formation. Spices, sodium benzoate, benzoic acid, mint flavoring, and harmless green coloring may be used provided their presence is suitably declared on the label.

The quality of apple jelly is determined on the basis of consistency, color, and flavor. In order to meet the requirements for U. S. Grade A (Fancy), apple jelly must have a tender to slightly firm texture and retain a compact shape without excessive syneresis ("weeping"). The color must be bright and typical of apples, with no more than a slight cloudiness. The flavor must be distinct and normal. A soft or excessively firm texture, a dull or cloudy color, or a poor, caramelized flavor detract from the grade.

2. APPLE JAM

The terms *jam* and *preserve* are frequently used synonymously although these products may differ on the basis of the size of fruit pieces present. Preserves may retain somewhat of the original form of the fruit as crisp pieces, whereas jams consist of fruit in the form

of pulp. Although jams may be prepared from apples by accepted procedures, Federal regulations do not recognize apples other than crabapples as a sole ingredient in jams or preserves. *Crabapple Jam,* or *Crabapple Preserve* is the viscous or semisolid food made from a mixture of not less than 45 parts by weight of crabapples to each 55 parts by weight of sugar ingredient. Such mixture, with or without the addition of water, is concentrated by heat to such a point that the soluble solids content of the finished product is not less than 68%. The crabapples used are mature, properly prepared fruits which may be fresh, frozen, or canned.

In addition to the use of crabapples for preparing preserves or jams, apples may be used in combination with one or more other specified fruits, provided that no one fruit constitutes less than one fifth of the total fruit mixture, with the exception of pineapple which may constitute not less than one tenth of the mixture, and provided that apples constitute no more than one half of such mixtures. When such mixtures are used the product is labeled *Mixed Fruit Preserves* or *Mixed Fruit Jams* or the names of the fruits used may precede the term preserve or jam in the order of their predominance. Optional sugar ingredients that may be used are sucrose, invert sugar sirup, corn sirup, honey, or specified combinations of these with or without dextrose. The weight of these ingredients used is based on their solids content and when corn sirup or honey is used their presence must be declared on the label. Pectin and certain specified organic acids may be added to compensate for deficiencies of these substances in the fruits used and sodium citrate and sodium potassium tartrate may be added in specified amounts. Spices and sodium benzoate or benzoic acid may be added provided their presence is suitably declared on the label.

3. APPLE BUTTER

Apple butter is the smooth, semisolid food made from a mixture composed of not less than 5 parts by weight of apples to each 2 parts by weight of sugar ingredient, provided that no sugar ingredient is required when fruit juice in quantity not less than one half of the weight of the apple is used. Such mixture is concentrated by heat to such a point that the soluble solids content of the finished butter is not less than 43%. In addition to apple butter, apples may be used in preparing *Mixed Fruit Butters* by combining apples with one or more specified

fruits, provided that no one fruit shall constitute less than one fifth of the fruit ingredients. The individual fruits used in preparing mixed butters may precede the word butter in the order of predominance.

The fruits from which butters are made are prepared by cooking fresh, frozen, canned, or dried mature fruits, with or without the addition of water, and by screening out skins, pits and cores. When dried fruit is used in preparing butter this fact must appear on the label. The weight of optional fruit ingredients used is calculated from the soluble solids content of the ingredients used, exclusive of added solids, on the basis of the soluble solids of the fresh fruit. In using fruit juices the weight of fruit juice, whether concentrated, unconcentrated, or diluted, is calculated on a similar basis, and when fruit juices are used their presence must be indicated on the label. Optional sugar ingredients that may be used are sucrose, invert sugar sirup, brown sugar, invert brown sugar sirup, honey, corn sirup, or specified combinations of these with or without dextrose. The weights of these ingredients to be used are based on their solids content and when honey or corn sirup is used their presence must be declared on the label. Spices, flavoring (other than artificial), salt, vinegar, lemon juice, lime juice, and specified organic acids may be added as optional ingredients provided requirements as to labeling are met.

The quality of apple butter is determined on the basis of color, absence of defects, consistency, finish, and flavor. U. S. Grade A (Fancy) apple butter possesses a uniform, polished, dark chocolate brown color which may possess a reddish shade, and is practically free from defects such as black specks, particles of seeds, or similar defects. The consistency must be such that the butter forms a prominently mounded mass but is not so thick as to prevent its being spread readily. The finish must be fine grained, evenly divided, smooth, and free from lumps. The flavor must be free from any traces of bitter, scorched, caramelized, molasses-like, or noticeable brown sugar flavor, or objectionable off-flavors.

4. CANDIED APPLES

Candied apples may be defined as a confection prepared by impregnating pieces of apple with sugar sirup and then drying to overcome stickiness. The process is so conducted that the pieces retain essentially their original shape. The candied fruit may be *glacéd* by coating it with concentrated solution of sugar and confectioner's

glucose sirup followed by careful drying to give a transparent glaze to the surface.

5. APPLE CANDY

Apple candy may be defined as candy confections containing apples as an ingredient. In such products apples may contribute to the flavor and also to the texture through the formation of pectic gels.

C. Apple Jelly

1. PRINCIPLES OF GEL FORMATION

The consistency of fruit jellies depends entirely on the formation of a pectin gel which distinguishes these products from fruit sirups. Because of the importance of consistency in the quality of these products accurate control of the various factors contributing to consistency is essential in their commercial preparation. In order to achieve the desired texture in a jelly it is necessary that those conditions required for the formation of a pectin gel of suitable consistency be met in its preparation.

Role of Pectin. Pectin, as it occurs in fruit and in pectin preparations, represents a wide range of compositions which vary in gel-forming properties. The various pectic substances have been classified in Chapter V (page 58). Of these substances the *water-soluble pectinic acids* of varying methyl ester contents and varying degree of neutralization which are capable of forming gels with sugar and acid under suitable conditions are of greatest importance in preparing a fruit jelly. When properly combined with sugar, water, and acid these substances will form a gel structure.

The quantity of pectin necessary for gel formation varies and depends on the source of the pectin and its treatment prior to gel formation. The size of the molecules present and their degree of esterification are important factors in determining its colloidal properties. It is therefore meaningless to refer to the quantity of pectin in reference to jelly manufacture without also indicating its gel-forming quality. Commercial pectin preparations are usually sold on the basis of *jelly grade,* which is the number of pounds of sucrose that one pound of the preparation will gel under standard conditions of acid and water contents. The gelling properties of pectin prepara-

tions and fruit juices can be determined accurately only by making trial gels under controlled conditions, although the viscosity of a fruit juice extract may be used as an index of gelling power under suitable conditions.[834] For a given pectin preparation a definite minimum quantity must be present if a gel structure is to result. Above this minimum the firmness of the gel increases with increasing pectin concentration.

Sugar. In order for a sugar–acid–pectin mixture to gel in a water solution, sugars must be present in a definite, minimum amount which is determined in part by the quality of the pectin. For practical purposes in the manufacture of apple jelly the sugars must be present to the extent of somewhat over 60% so that they, together with other soluble solids present, will produce a product of at least 65% soluble solids as required by Federal regulations. The firmness of a given gel increases with increased sugar content and decreases with decreased sugar content.

Acid. Acid is a necessary ingredient in the preparation of a pectin gel, and is an important factor in determining texture. The acid content should be such that the final gel has a *p*H of about 3.3. The consistency of the gel can be controlled to a certain extent by varying the quantity of acid present. Increasing the acid content results in a firmer gel whereas reducing the concentration of acid results in a weaker gel. The lower practical limit for *p*H is about 3.1, below which the gel tends to lose water, a phenomenon known as *syneresis* or *weeping.*

2. JELLY MANUFACTURE

Preparation of Juice. In preparing apple and other fruit jellies the water, sugar, acid, and pectin naturally present in the fruit are used, wholly or in part, to produce a gel structure. The various other flavor, aroma, and color components of the fruit contribute those qualities that make the gel characteristic of the fruit from which it is prepared and make the product a fruit jelly. These constituents are removed from the fruit in the form of an extract which may be prepared by one of several procedures. The method by which the extract is prepared and concentrated determines to a large extent the flavor of the finished jelly.

Apple juice, prepared by the method described in Chapter XII

[834] G. L. Baker, *Food Inds., 6,* 305, 315 (1934).

TABLE 48. Composition of Heat-Extracted Apple Juice (8 Varieties)[835]

Extraction Period, 15 Minutes at 212°F.

Extraction	No. of tests	Composition											
		Ratio of Fruit to Water											
		3:2				3:3				3:4			
		Soluble solids		Pectin[a]		Soluble solids		Pectin		Soluble solids		Pectin	
		In juice, %	Recovery, %[b]	In juice, %	Recovery, %	In juice, %	Recovery, %	In juice, %	Recovery, %	In juice, %	Recovery, %	In juice, %	Recovery, %
First extraction	27	8.2	49	0.226	42	6.7	53	0.161	43	5.7	58	0.150	44
Second extraction	27	5.3	26	0.170	23	3.7	24	0.122	25	2.9	26	0.111	25
Third extraction	27	3.2	12	0.109	11	2.0	12	0.084	11	1.5	8	0.65	15
Residue pulp	24	3.1	13	0.240	25	1.9	12	0.195	21	1.7	8	0.170	16

[a] Pectin calculated as pectic acid.

[b] By recovery is meant the percentage of the total soluble solids, pectin, etc., present in the apples which is obtained by the use of 1, 2, or 3 successive extractions or which remains in the residual pulp.

(pages 323–329) may be used in preparing jelly. The soluble pectic substances that accompany cold-pressed juice are of poor jelly quality, however, and it therefore is necessary to add a pectin preparation to such juice or to concentrate the juice to about one sixth its original volume to obtain a suitable gel structure. To obtain the benefits of the rather high protopectin content of apples in jelly manufacture it is the general practice to heat the fruit prior to pressing to accomplish a restricted hydrolysis of this protopectin into soluble pectin of high jelly quality. In preparing an extract by the hot process the sliced or chopped apples are cooked soft, either by steaming or by the addition of water and boiling in a suitable pan. Either fresh, frozen, or canned apples may be used in preparing the extract and the flavor of the finished jelly depends to a considerable extent on the quality

TABLE 49. Yield and Composition of Juice and Jelly per Unit Weight of Apples. Average of Combined First and Second Extractions at 212°F. with 8 Varieties[835]

Ratio of Apples to Extraction Water 1:1

	Juice					Jelly			
Extraction period, minutes	No. of tests	Yield per lb., ounces	Total soluble solids, %	Pectin,[a] %	Acidity as malic, %	Pectin, %	Yield per lb., ounces	Jelly strength, grams	Jelly grade[b]
15	16	30.7	5.70	0.144	0.212	0.283	20.02	88	1
15–10[c]	5	31.8	5.67	0.143	0.235	0.272	19.90	90	1
30	12	27.2	6.08	0.175	0.250	0.318	19.90	95	1–2
60	5	28.1	6.55	0.177	0.300	0.317	18.33	57	2–3

[a] Pectin calculated as pectic acid.
[b] Grade 1—good; Grade 2—fair; Grade 3—poor, unmarketable.
[c] 15 minute extraction followed by 10 minute standing period.

and varieties of fruit used. A study of the suitability of Eastern-grown varieties for jelly showed that most mildly acid to acid red varieties possessing a strong apple flavor were suitable.[835,836] Coarsely sliced apples were found preferable to chopped or grated fruit because of greater ease of pressing or filtration, clearness of the juice, and less discoloration. A ratio of apple to water from 1:1 to 3:2 was considered best for juice extraction. Of several extraction periods studied, 15 minutes at 212°F. proved the best. A second extraction of the

[835] C. R. Fellers, *Fruit Products J., 8* (1), 10 (1928).
[836] C. R. Fellers, *Mass. Agr. Expt. Sta. Research Bull., 15,* 1925, pp. 218–251; *Tech. Bull. 14,* 1928.

pulp or marc was found desirable because more than half as much pectin was obtained in the second extraction as was recovered in the first. Table 48 shows the composition of the heat-extracted juices obtained from 8 varieties and Table 49 presents data on the yield and composition of juice and jelly using varying times of extraction. The addition of polyphosphates and acid to the cooking water has been found to increase the jelly value of the resultant extract by about 62%.[837]

The hot mixture is pressed in a manner similar to that used in preparing fresh juice (page 325) and the once pressed promace may be reheated with water and repressed to increase the recovery of soluble solids and pectin, when fruit costs warrant. In small operations the cooked pulp may be placed in cloth bags and the extract allowed to drain off. The prepared extract or juice may be preserved for future use by freezing or by pasteurizing in hermetically sealed containers, or it may be concentrated by evaporation or freezing to save storage and shipping costs. The soluble solids content of the juice is used in calculating the proportion of juice to sugar, to correct for water added during its preparation or removed during previous concentration. This calculation is based on an assumed average soluble solids content of 13.33% for pure apple juice.

Extracts of other fruits than apple, which may be used in preparing mixed fruit jellies in combination with apples, are prepared in much the same way as has been described for apples. The use of about 20% Japanese quince has been found to improve the flavor of apple jelly and is also useful in increasing the acidity and pectin content of juice extracts.[838] Jellies prepared from crabapples and rose hips, which are very high in ascorbic acid content, retain a high concentration of this vitamin.[839] Fruits such as berries are heated for a shorter period and the addition of water is usually not necessary. Such extracts are blended with apple extracts before concentration and finishing in preparing mixed fruit jellies containing apples.

Clarification. Fruit juice extracts are usually strained through cloth and allowed to settle in order to remove suspended solids that would otherwise contaminate the jelly. When necessary the super-

[837] G. L. Baker and G. M. Gilligan, *Food Packer, 27* (6), 56 (1946).
[838] A. S. Levine, *Fruit Products J., 21* (6), 177 (1942).
[839] J. Tuba, G. Hunter, M. J. Hutchinson, and L. L. Kennedy, *Can. J. Research, 21c,* 363 (1943); *Chem. Abstracts, 38,* 1575 (1944).

natant juice may be centrifuged or filtered with the aid of diatomaceous earth. Starch is one of the principal contributors to turbidity in jelly. When present in the extract it may be necessary to use starch-hydrolyzing enzymes before a clear jelly can be obtained. The use of clarifiying agents such as pectin-splitting enzymes is not practical since these preparations destroy the jelly quality of the pectin.

Soluble Solids Content. It is possible to prepare apple jelly by boiling cold-pressed juice to about one sixth of its original volume and allowing the concentrate to cool. The prolonged boiling necessary to obtain the required solids content for gel formation produces a product that is dark in color and has a tart, caramelized flavor free from a characteristic apple aroma. Prolonged boiling also decomposes the pectin, making consistency unpredictable, and the product may be sirupy or gummy and tough. The yield per volume of fruit is low. By conducting the evaporation under vacuum the color and flavor are improved but the product remains tart because of the high concentration of acid realized during evaporation.

More of the natural apple flavor is retained and greater yields of jelly are obtained by adding sugar to the juice so that only slight boiling is necessary to produce the required solids content. Whereas concentration of apple juice to the soluble solids content necessary for gel formation results in a strongly flavored jelly, that produced from the minimum of 45 parts of juice to 55 parts of sugar allowed by Federal regulations tends to lack color and a characteristic apple flavor. By selecting a formula between these two extremes jelly with a desirable color and flavor can be prepared in good yield. A product, termed cider apple jelly, has been proposed which is prepared by mixing fresh apple juice, concentrated to one third its original volume, with the heat-extracted juice from an equivalent weight of apples and adding dry sugar to about 60% of the weight of this stock.[840]

The most common sugars added are sucrose, glucose, invert sugar sirup, corn sirup, and honey. Of these sucrose, invert sugar sirup, and high conversion corn are suitable for use alone. Glucose cannot be used in amounts greater than one fourth of the total amount of sugar added without danger of crystallization during storage and jellies prepared from ordinary corn sirup alone may not be sufficiently

[840] S. G. Davis, C. R. Fellers, and A. S. Levine, *Fruit Products J., 21* (9), 260, 283 (1942).

sweet.[841] Honey imparts a highly characteristic flavor to jellies when used as the only sweetening agent.

The formula used in preparing jellies depends on the individual operator. Unless the jelly maker has had experience with the juice extracts on hand trial jellies are usually made in which the proportion

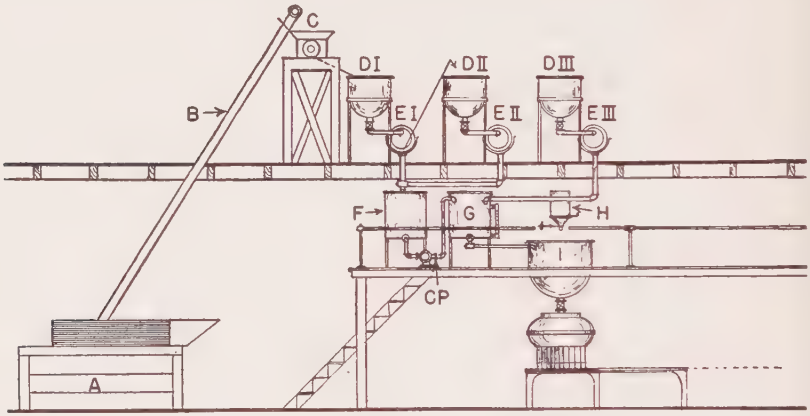


Fig. 87. Flowsheet for manufacture of cider apple jelly.[840] 100 pounds of apples are charged into apple washer A, sent via elevator B, to grater C, from grater to kettle DI, 15 gallons of water added, and the mixture boiled for 15 minutes. Extract is run through rotary strainer E, fitted with double cloth, and pulp charged into kettle DII, 10 gallons of water added, and boiled 10 minutes. Extract discharged through strainer E into tank F. (G, tank for mixed extracts and concentrated juice; CP, centrifugal pump to transfer liquid from tank F to tank G; H, sugar dosing apparatus; I, jelly kettle.) 10 gallons of apple juice are run into kettle DIII and concentrated 3:1 or 2:1. In place of open kettle concentration a vacuum pan may be installed. Concentrated juice is discharged through strainer E fitted with 4 cloths into jelly kettle I. Cook to jelly of 68% soluble solids and run jelly to filling machine below jelly kettle with preheater attachment. The plan may be dimensioned to suit any desired production (courtesy Avi Publishing Co.).

of sugar added is varied to determine the amount of sugar the extract will gel. The jelly value of the extract may also be estimated on the basis of the viscosity of the extract or its content of alcohol-insoluble material. When these tests indicate that the extract is not sufficiently rich in pectin to produce a jelly with the desired proportion of extract

[841] D. K. Tressler, *Fruit Products J., 19,* (8), *228,* 251 (1940).

and sugar, the required amount of a pectin preparation is added. It is also necessary to determine the acidity of the extract to assure that the finished jelly will be within the optimum *p*H range for gel formation. The amount of acid required may be determined by trial jellies or by titration of the extract with standard alkali. An acid concentration between 0.75 and 1.0% is desirable in the finished jelly.

When the desired formula has been ascertained the proper proportions of fruit extract and sugar are combined and heated to boiling in a steam-jacketed pan. If pectin is included in the formula it may be added to the fruit juice ingredients in the form of an extract or a solution may be prepared from dried pectin by mixing it with 6 to 10 times its weight of sugar and dissolving in warm water. The mixture of fruit juice, sugar, and pectin is then boiled as rapidly as possible, to avoid loss of flavor and hydrolysis of pectin, until final concentration is accomplished. Small kettles are usually preferred because of the shorter boiling time required. Organic material that coagulates during the boiling operation is skimmed off.

Finishing. The final soluble solids content of a jelly is controlled by the amount of water that is removed during the boiling operation. This operation must be interrupted at the proper point because of the importance of soluble solids content to the texture of the finished jelly. The finishing point may be determined by means of a refractometer, by rise in boiling point, or by use of a hydrometer, all of which are indexes of the soluble solids content of the boiling mixture. Of these the refractive index is the most accurate and the hydrometer least reliable. A boiling temperature at the finish point from 8° to 9°F. above that of pure water indicates a soluble solids content of about 65 to 67%. Perhaps the most common method of determining the end point in commercial operations is by the "spoon" or "sheet" test which is made by observing the behavior of the mixture when allowed to flow from a spoon or paddle. If the boiling mixture drips as a thin sirup further concentration is necessary until it partly congeals and drops from the spoon or paddle in sheets. Although this test indicates not only that concentration has been sufficient but that the pectin and acid concentrations are adequate to cause gel formation, considerable experience and skill are required in applying the test in commercial jelly manufacture.

Acid, spices, mint flavor, or preservatives, when used, are added

to the jelly just before pouring. The apple flavor of the jelly is greatly enhanced by the addition of apple essence (page 370).[845] Sodium citrate or sodium potassium tartrate may be added, in amounts up to 3 ounces for each 100 pounds of sugar used, to delay the time of setting and prevent premature gel formation in the kettle or during filling of the containers.

Packaging. Glass jars of various sizes and shapes are most commonly used for packaging jellies but enameled tin cans and wooden tubs are also used, particularly for institution and bakery use. It is in the large institution-sized containers that preservatives are most frequently used because of danger from contamination during filling and difficulties in sealing. The finished jelly may be filled hot and sealed by automatic machines. When the containers are sealed at temperatures exceeding 185°F., pasteurization is not necessary but a short heat treatment is usually given to assure sterilization of the jar and closure. The filled containers are cooled to avoid overheating with resultant loss of flavor and to permit casing from the packaging line.

D. Apple Jam

Jams and preserves may be prepared from apples of the dessert and culinary varieties but such products do not possess a distinctive flavor and Federal regulations (page 422) do not recognize such varieties as the sole fruit ingredient in jams or preserves. Jams and preserves may be made with crabapple varieties as sole fruit ingredients under these regulations, however and mixed fruit jams may be prepared in which up to one half of the fruit ingredients are apples. The same general principles outlined under jelly manufacture apply in the preparation of jam but insoluble solids from the fruit are included with the juice in its preparation. These insoluble solids contribute to the texture and consistency of the product and more leeway may be found in these qualities in the finished product.

JAM MANUFACTURE

Preparation of Fruit. Fresh, frozen, or canned apples may be used in preparing jams. The sliced or chopped fruit is heated with water until soft and may be pulped by passing through a coarse screen before mixing with other fruit ingredients. Unless the screen to be

[841a] E. L. Griffin, F. B. Talley, and M. E. Heller, *ibid., 27* (1), 4, 27 (1947).

used in pulping is sufficiently fine to remove skins and core material the fresh fruit is peeled and cored before heating. In calculating the proportion of fruit to sugar, the weight of the fruit, exclusive of any sugar, water, or other substance added for any processing or canning or otherwise, is deducted from the weight of the pulp; the weight of seeds, skins, cores or other parts that may be removed in preparation is not included in the weight of the fruit used.

Concentration, Finishing, and Packaging. Preliminary tests are made to determine the gelling properties of the fruit mixture from which the jam is to be made and the final formula is based on the same considerations as outlined under jelly manufacture. When the desired formula has been ascertained the sugar, fruit, and pectin, if required, are mixed and boiled to accomplish final concentration. Federal regulations prescribe that the soluble solids content of jams containing crabapples shall not be less than 68%. The end point is determined in the same way as for jellies. Spices, acid, and preservatives, when used, are added during the final stages of concentration. Salts used in jellies to delay gel formation are not commonly added to jams and preserves because a delay in setting would permit suspended fruit solids to separate. Packaging and preservation methods used for jellies are also used for jams and preserves.

E. Apple Butter

1. TYPES OF BUTTER

The color, flavor, and consistency of apple butters vary considerably depending on the procedure used in their preparation and the optional ingredients used. One of the main differences in the quality of apple butters depends on the relative proportion of soluble solids that is contributed by apples. Commercial apple butters may be divided into two types on the basis of the methods used in their manufacture and on their quality. Both types comply with Federal standards (page 422) of identity.

Home Style. "Old-fashioned" or "home-style" apple butter is dark brown, tart, and has a pronounced and characteristic flavor. Its consistency is almost solid. The soluble solids of such butters are usually derived wholly from apples, and yields per volume of fruit are low. It is doubtful if modern food technologists, with their emphasis on rapid, low-temperature handling to preserve natural fruit flavors,

would have invented the highly flavored and popular home-style product, because the characteristic qualities of this product are due in large measure to oxidation during preparation and caramelization through prolonged high-temperature boiling. Nonetheless, the home-style product is generally considered superior because of this flavor.

Sauce Type. Sauce-type butter is prepared from a mixture of fruit pulp and sugar in such proportions that not less than 5 parts of fruit pulp is used for each 2 parts by weight of sugar. The consistency of such butters is relatively thin, and the tart, characteristic, full flavor is lacking, The products are usually lighter in color than home-style butter.

2. BUTTER MANUFACTURE

Preparation of Fruit. Apples used in preparing butter may be fresh, canned, or frozen, and dried apples or chops may be used provided their presence is declared on the label. The fruit is cooked with water until soft and then pulped by passing through a fine screen to remove seeds, skins, and core material. When whole apples are used some difficulty may be encountered because of the presence of seed cell and calyx parts that may pass through the screen and become defects in the finished butter. The economy, ease of handling, and year-around availability of apple chops have made this product an increasingly important source of apple ingredient for butter. When prepared without the use of sulfur dioxide they contribute to the dark color desired. The dried fruit is prepared by adding water, cooking, and pulping in the same way as for the fresh fruit. The proportion of fruit pulp to juice or sugar to be used is calculated on the basis of the soluble solids content of the pulp, with pure apple pulp considered to contain 13.33% soluble solids. Pulp from other fruits is mixed with apple pulp in the preparation of mixed fruit butters. In such butters the apples are usually employed as an extender for more expensive fruits, and boiled apple juice may be added to increase acidity.

Apple pulp may be mixed with sugar or with apple juice, depending on the type of butter prepared. Apple juice, when used, is usually added in the form of boiled cider which has been prepared by the procedure outlined in Chapter XII (page 366). The proportion of juice to fruit used varies from the Federal specified minimum, in which juice equal to one half the weight of fruit pulp is added, to as high as 6 parts of apples used in preparing juice to 1 part used in preparing

pulp. Yields may be as low as 2 to 3 quarts of butter per bushel of apples when the proportion of juice is high. Sucrose, invert sugar sirup, brown sugar, invert brown sugar sirup, honey, and corn sirup may be used as optional ingredients in preparing sauce-type butter, provided that not more than 2 parts of sugar may be added to each 5 parts, by weight, of fruit. High-conversion corn sirup has been found to be a suitable substitute for sucrose in preparing quality fruit butters.[842] The use of brown sugar or invert brown sugar sirup imparts a special flavor to this product.

Commercial butters may vary in composition between the two extremes represented by home-style and sauce-type butters, depending on the proportion of apple juice used in its preparation and on the degree of concentration. A procedure for producing quality apple butter with good yields has been proposed which uses a weight ratio of sugar : sauce : boiled cider of 1 : 6 : 6, calculated to a fresh-weight basis for the apple ingredients from their soluble solids content.[843] A darkened sauce was produced by agitating the ground raw pulp, and an improved consistency was realized which was attributed to more efficient pectin extraction during the oxidation process. The dark color is increased and a caramelized flavor developed by overcooking the butter to a high concentration, with a portion of the sauce and cider reserved for later dilution to a soluble solids content of 50 to 53%. Yields of from 8 to 9 quarts of butter per bushel of apples were realized by this process.

Concentration, Finishing, and Packaging. The mixed fruit, juice, and sugar ingredients are concentrated by boiling until the desired consistency is obtained and the soluble solids content is at least 43%. Spices, flavoring, salt, and acids in the form of vinegar, lemon juice, lime juice, or permitted organic acids, when used, are added in the final stages of concentration to avoid flavor loss. The hot, finished butter is usually filled into containers and sealed without further pasteurization but additional heating is desirable, particularly with butters of low solids content, to assure preservation.

F. Candied Apples

Apples are not considered particularly suited for candying and this product is not an important by-product of this fruit. Occasional

[842] D. K. Tressler, *Fruit Products J., 19* (8), 228, 251 (1940).
[843] C. S. Nevin and H. H. Mottern, *ibid., 24* (8), 228, 253 (1945).

interest is shown in candied apples as a specialty confection in the United States but their preparation is more common in the British Empire.

METHODS OF MANUFACTURE

Preparation of Fruit. Firm fleshed apples are peeled, cored, and sectioned by methods outlined in Chapter XI (page 283). The sections may be used fresh or preserved by canning (Chapter XI, page 296), or with sulfurous acid (Chapter XI, page 311). Special treatments are usually employed to increase the firmness of the flesh. The fresh fruit is blanched in hot water to soften the flesh and permit sugar penetration. Blanching may be carried out in a dilute alum solution to increase firmness or the blanched pieces may be chilled in cold water and then soaked in dilute alum. When preserved by canning it is advantageous in later processing if the fruit is packed in a heavy sirup which serves to increase its sugar content and firmness. Calcium salts are commonly added to increase the firmness of apples preserved in sulfurous acid. Before candying, the fruit is drained from the brine and leached with hot water to remove the sulfurous acid. The prepared fruit may be dyed by heating with suitable dyes in solutions containing acids to secure even penetration of the dye.[844]

Candying Process. The candying process consists of impregnating the fruit cells with sugar. To avoid osmotic shrinking this is usually accomplished by steeping in successively heavier sugar sirups until the pieces become saturated with sugar. They are then drained from the sirup and dried to overcome stickiness. When conducted on a small scale the process requires considerable tedious hand labor to avoid withering of the fruit by the sugar sirup and breaking up of the fruit pieces. The preheated and cooled fruit is covered with a hot 30% sugar solution, preferably containing some corn sirup to prevent the candied product from becoming tough and hard on storage. The fruit is held in this sirup for 12 to 48 hours to permit sugar penetration. The sirup is then removed by draining, sugar is added to increase its concentration from 5 to 10%, and it is then reheated and poured over the fruit. After the required steeping period the sirup is again removed and its concentration again increased; this process is repeated until the sirup finally has a concentration of about 65% sugar. In large-scale operations it is possible to eliminate much of the hand labor

[844] F. E. Atkinson and C. C. Strachan, *Fruit Products J., 20* (6), 166, 185 (1941).

by means of a continuous candying process. The fruit is covered with the initial sugar solution which is then circulated through the steeping tanks. The sirup concentration is continuously increased by evaporation of water before returning to the tank, until the final concentration is reached.

Drying and Glacéing. The fruit is held in the final, heavy sirup for about three weeks to permit it to plump and become impregnated with sugar. It is then drained, excess sirup is removed by dipping momentarily in hot water or washing with a wet cloth; and the pieces are dried until no longer sticky. Drying is accomplished either by spreading on a screen and holding at room temperature or by artificial drying in ovens at from 120° to 140°F.

Candied fruit is usually coated with a thin, transparent layer of sugar by a process known as *glacéing*. The candied pieces are dipped into hot sirup, drained, and dried. The sirup may be prepared by partial inversion of sucrose or by mixing sucrose and corn sirup, and should be concentrated to have a boiling range from 270° to 290°F.

G. Apple Candies

Candies containing apples as an ingredient are specialty confections and their method of preparation depends on the ingenuity of the individual candy maker. Dried or candied apples may be incorporated into mixtures with nuts or other dried fruits for use as centers in chocolate or in the preparation of fruit bars. Apple juice extracts may be used in preparing stiff pectin jellies containing nuts, flavoring, and other suitable ingredients. The addition of apple essence (page 370) has been found to improve the quality of this type of product.[845] These jellies may be covered with chocolate or dusted with powdered sugar to overcome stickiness.[846] A process has also been developed for combining milk and apple juice or pulp to yield confections having a caramel-like consistency and good apple juice flavor.[847]

[845] E. L. Griffin, F. B. Talley, and M. E. Heller, *Fruit Products J., 27* (No. 1), 4, *27* (1947).

[846] T. H. Abell, *Utah Agr. Coll. Expt. Sta. Bull., 179,* (1921). W. V. Cruess and R. F. Celmer, *Fruit Products J., 18* (2), 43, 52, 54 (1938). W. V. Cruess, *ibid., 19* (6), 164, 174 (1940).

[847] F. C. Uilbrandt and R. D. Sieg, *Ind. Eng. Chem. News Ed., 18,* 897 (1938).

CHAPTER XV

APPLE POMACE

Apple pomace consists of the press cake resulting from pressing apples for juice, including the press cake obtained in pressing peel and core waste from the preparation of apples for canning; drying, and freezing. Between 500 and 700 pounds of wet pomace are obtained from each ton of apples pressed in the manufacture of juice, juice concentrate, cider, wine, brandy, and vinegar. Production is distributed throughout those areas in which these products are made and it is available in fresh form during the normal pressing season, beginning in September and continuing into the following year. Apple pomace is becoming an increasingly important product of apples and practically the entire production finds a market. Its value rests mainly in its content of carbohydrates and its principal uses are as stock feed and in the preparation of pectin. Unless suitable methods of preservation are employed the freshly pressed pomace must be used as soon as it is prepared because its high water content results in rapid destruction by microorganisms.

A. Composition

Fresh apple pomace differs in composition from apples mainly in that it has a slightly higher content of insoluble solids and a slightly lower water content. It may be assumed that the juice remaining in once-pressed pomace, which constitutes about four fifths of its weight, has essentially the same composition as the expressed juice. The remaining constituents consist of insoluble material of the apple flesh, and seed, core, skin, and stem parts that are not affected by the pressing operation. The composition of wet and dried pomace is shown in Table 50.

In addition to the constituents shown in Table 50 the pomace usually contains residues from insecticide sprays used in producing

apples. When present in excessive amounts these residues considerably depreciate its value for feed and food purposes. Because the pomace represents a concentration of these insoluble residues over that present on the fruit from which it is pressed, it is necessary to give

TABLE 50. Composition of Apple Pomace

Constituent, %	Fresh apple pomace[a]	Dried apple pomace[b]
Water	66.39–78.15	11.00–12.50
Carbohydrates	9.5–21.98	—
Nitrogen-free extract	—	54.77–59.29
Pectin	1.5–2.5[c]	15.0 –18.0[c]
Crude fiber	4.3–10.5	15.33–20.55
Proteins	1.03–1.82	4.45–5.67
Fat (ether extract)	0.82–1.43	3.75–4.65
Ash	0.56–2.27	2.11–3.50
Potassium (as K_2O)	0.2–0.6	—
Phosphorus (as P_2O_5)	0.4–0.7	—

[a] From B. T. P. Barker and C. T. Gimingham, *J. Board Agr., 22,* 851; *J. Soc. Chem. Ind., 35,* 135 (1916); *Chem. Abstracts, 10,* 2273.
[b] From C. Brioux, *Ann. fals. et fraudes, 19,* 142 (1926); *Chem. Abstracts, 20,* 2033.
[c] From C. P. Wilson, *Ind. Eng. Chem., 17,* 1065 (1925).

particular attention to this problem in the preparation of pomace products. Methods have been developed for the removal of lead[848] and arsenic[849] by precipitation from solution, but special washes prior to pressing remain the most practical solution when the fruit contains excessive amounts of residue.

B. Preservation

The concentration of pomace in areas where apples are processed in large quantities during a few months often results in local, seasonal surpluses which make some method of preservation necessary. The most common method of preservation consists in drying, but temporary preservation by means of chemicals, mainly sulfur dioxide, may be resorted to when drying facilities are not adequate. Drying, usually to less than 12% moisture, not only preserves the pomace but simplifies packaging, storage, and transportation, thereby greatly reducing

[848] V. E. Speas, N. M. Mnookin, and A. C. Metcalf, U. S. Pat. No. 2,070,870, Feb. 16, 1937.
[849] V. E. Speas and N. M. Mnookin, U. S. Pat. No. 2,080,582, May 12, 1937.

the cost of handling this product. Preservation by fermentation to produce ensilage is a commonly used procedure when the pomace is to be used as a stock feed.

1. DRYING

Apple pomace is dried in kiln-type driers in a manner similar to that outlined for apples in Chapter XI, but drying by means of continuous, rotary driers is preferred as more efficient in the use of labor and fuel.[850] Several types of rotary driers are in use. All subject the pomace to agitation and heat in the presence of a stream of air as it is moved progressively from the wet to the dry end of a large drum. Heat may be supplied by steam pipes within the drum or by hot gases passed through the drying material. Care is taken that the pomace temperature does not exceed 160°F. during the drying operation to avoid decomposition of carbohydrate material or deterioration of the pectin.

2. CHEMICAL PRESERVATION

Apple pomace intended for use in the preparation of pectin must be processed soon after pressing because the pectin quality of wet pomace deteriorates rapidly. When some delay in processing or drying is necessary temporary preservation of the jelly quality of wet pomace may be obtained by treatment with 1500 p.p.m. of sulfur dioxide, especially for the first three days.[851] Temporary preservation has also been reported possible by impregnating the pomace with a 6% by weight, solution of phosphoric acid at concentrations of 5 to 10%, and ramming the mixture into containers.[852]

3. FERMENTATION

The feeding value of apple pomace is in many cases more economically preserved by fermentation processes than by drying and considerable quantities are preserved for feed use in the form of ensilage. The pomace may be ensiled alone or mixed with alfalfa, corn silage, grass clippings, or other suitable material. Some workers have rec-

[850] J. Credo, *Fruit Products J., 5* (6), *22,* (7) 8 (1926).

[851] V. L. S. Charley, L. F. Burroughs, M. E. Kieser, A. Pollard, and J. Steadman, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1942,* 89; *Fruit Products J., 24* (1), 4 (1944).

[852] Pomosin-Werke Komm.-Ges. Fischer & Co., Belg. Pat. No. 444,952, Apr. 30, (1942); *Chem. Abstracts, 39,* 565.

TABLE 51. Average Composition and Digestible Nutrient of Apple Pomace Products[a]

Source	Total dry matter, %	Digestible protein, %	Total digestible nutrients, %	Nutritive ratio 1:	Average composition					
					Protein, %	Fat, %	Fiber, %	N-free extract, %	Minerals, %	No. of analyses
Apple pomace, wet	21.1	0.5	16.0	31.0	1.3	1.3	3.7	13.9	0.9	29
Apple pomace, dried	89.4	1.7	60.5	34.6	4.5	5.0	15.6	62.1	2.2	7
Apple pectin pulp, wet	16.7	0.6	9.7	15.2	1.5	0.9	5.8	7.9	0.6	4
Apple pectin pulp, dried	91.2	2.6	55.0	20.2	7.0	7.3	24.2	49.4	3.3	6
Apple pomace silage	20.9	0.6	15.5	24.8	1.6	1.3	4.4	12.6	1.0	15

[a] From F. B. Morrison, *Feeds and Feeding*, 20th ed. Unabridged, Morrison, Ithaca, 1936, pp. 974, 976, 977.

ommended the addition of up to 15% of agricultural salt in preparing pomace for ensiling[853] but this practice has not generally been found necessary. The material to be ensiled is tightly packed in air-tight pits or silos where it undergoes an anaerobic fermentation, forming lactic acid and carbon dioxide among other products. Studies have shown that cull apples may also be preserved in the form of ensilage by ensiling with alfalfa hay in the proportion of 80% of apples to 20% of hay.[854] Such a mixture was found to lose approximately 13% of dry matter, 7% each of protein and fiber, 31% of ether extract, 17% of nitrogen-free extract, and 3% of ash during fermentation. Over 16% of the dry matter loss was due to the evolution of carbon dioxide. Ensiling of chopped apples alone resulted in considerable loss by drainage and the product had a high moisture content.

C. Utilization

1. FEEDING VALUE

Apple pomace may be fed fresh, as silage, or as dried pomace. Besides regular pomace the residue remaining after pectin extraction, referred to as *pectin pulp*, is also used as feed. Numerous investigators have reported on the value of the various pomace products as feed. In general they have been found to be palatable, succulent feeds for cows and sheep. They are of questionable value for pigs and unsuitable for horses.[855] The palatability of dried pectin pulp has not been found to be uniformly good for dairy cows and it has been recommended that molasses be added to increase palatability.[856] Table 51 presents the average composition and digestible nutrients of various pomace products.

Feeding trials have shown some variation in the value of apple pomace products as compared with other feeds. Dried pomace appeared slightly more efficient as a milk producer than corn silage, whereas dried pectin pulp was found intermediate between good corn

[853] V. L. S. Charley, A. W. Ling, and E. L. Smith, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1942*, 101.

[854] J. C. Knott, H. K. Murer, R. E. Hodgson, and E. L. Overholser, *Wash. Agr. Expt. Sta. Bull.*, 362, 1938.

[855] J. B. Lindsey, C. L. Beals, and J. G. Archibald, *Mass. Agr. Expt. Sta. Bull.*, 205, 1921, pp. 135–144.

[856] P. B. Myers and G. L. Baker, *Delaware Agr. Expt. Sta. Bull.*, 160 (Tech. No. 10), 1929.

silage and beet pulp as a succulent feed for cows in one study.[857] Other studies have indicated that dried apple pomace was slightly inferior to beet pulp both on the basis of milk production and animal weight gain.[858] Feeding trials with sheep showed dried pomace to be fairly well digested, especially with respect to total dry matter, fiber, and extract matter, but protein and fat were poorly digested. It was slightly inferior to dried beet pulp and corn meal when fed to dairy cows as a component of the daily ration.[859] In still other studies dried apple pomace, when added to the basal ration of cows, caused a pronounced depression of the digestibility of the protein of the whole ration because of its high energy content.[860] The average digestion coefficients of wet and dried apple pomace, based on 6 and 7 trials, respectively, were: protein 37 and 37, fat 46 and 35, fiber 65 and 64, and nitrogen-free extracts 85 and 78 percent (respectively).[861] The average coefficients of digestibility of silage prepared from 80% whole apples and 20% alfalfa hay in a two-year study were found to be: dry matter 58, crude protein 52, crude fiber 49, ether extract 47, and nitrogen-free extract 70. On a dry basis the apple–alfalfa hay silage contained an average of 5.4% of digestible crude protein and 57.2% of total digestible nutrients. Ensilage prepared from whole apples alone caused an off-flavor in the milk when fed to dairy cows just before milking.[862] Some variations in the feed value of apples and apple pomace products might well be expected because of differences in methods of preparation and in quality of raw material. The feeding value of dried pomace has been found to vary according to the proportion of seeds and foreign material present and the method of preparation.[863]

[857] G. P. Walton and G. L. Bidwell, *U. S. D. A. Bull., 1166,* 1923, pp. 1–40.
[858] J. C. Knott, R. E. Hodgson, and E. V. Ellington, *Wash. Agr. Expt. Sta. Bull., 270,* 1932.
[859] J. B. Lindsey, C. L. Beals, and J. G. Archibald, *Mass. Agr. Expt. Sta. Bull., 205,* 1921, pp. 135–144.
[860] C. W. Holdaway, W. B. Ellett, J. F. Eheart, and M. P. Miller, *Virginia Agr. Expt. Sta. Tech. Bull., 32,* 1927, pp. 1–18.
[861] F. B. Morrison, Feeds and Feeding, 20th ed., Unabridged, Morrison, Ithaca, 1936.
[862] J. C. Knott, H. K. Murer, R. E. Hodgson, and E. L. Overholser, *Wash. Agr. Expt. Sta. Bull., 362,* 1938.
[863] F. Honcamp and E. Blank, *Landw. Vers. Sta., 92,* 275 (1919); *J. Soc. Chem. Ind., 38,* 300A; *Chem. Abstracts, 13,* 2940.

2. PECTIN FROM APPLE POMACE

It is not intended, in this chapter, to cover the extensive field of pectin chemistry and manufacturing technology; this subject has been adequately covered in a recent book.[865] A brief outline of the methods of pomace preparation and pectin extraction is presented in order to familiarize the student of apple technology with this important phase of apple utilization. Research being conducted on new and expanded uses for pectin and its products is also briefly reviewed.

Pectin Value of Pomace. Apple pomace varies considerably in pectin content and not all pomace is of suitable quality for pectin manufacture. A method for quantitatively estimating the pectin in dried pomace consists in making successive extractions of 5 g. pomace with dilute hydrochloric acid solutions followed by precipitation with methyl alcohol and final drying.[866] Pomace may be classified on the basis of the jelly units obtainable from it in a manner similar to that used in grading pectin preparations. By preparing an extract, making test jellies, and determining the strength of these jellies, all under standardized conditions, the pomace may be graded on the basis of the percentage of 100-grade pectin available.[867] Values for acceptable dried apple pomace, using this procedure, ranged from 25 to 35 grade. A rapid method for the evaluation and classification of apple pomace which involves a standard extraction procedure and examination of sugar–alcohol gels prepared from the extract has also been developed.[868]

Very little information is available regarding the pectin content of the pomace from different varieties of apples, or from apples grown in different producing areas. The maturity of the fruit from which the pomace is obtained is a factor in the quality of the pectic constituents present but losses of pectin have been reported as considerable only when apples are allowed to become overripe before pressing.[869]

The method by which pomace is handled after pressing has a

[865] Z. I. Kertesz, *The Pectic Substances.* Interscience, New York, *in preparation.*
[866] D. W. Stewart, *Analyst, 58,* 397 (1933).
[867] H. H. Mottern and E. E. Karr, *Fruit Products J., 25* (10), *292,* 313, 315 (1946).
[868] G. Jakovliv, *Ind. Agr. et aliment (Paris), 64,* 389 (1947); *Chem. Abstracts, 42,* 5134.
[869] V. L. S. Charley, L. F. Burroughs, M. E. Kieser, A. Pollard, and J. Steadman, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1942,* 89; *Fruit Products J., 24* (1), 4 (1944).

pronounced influence on the quantity and quality of pectin obtainable. Storage of small bulks of wet pomace in closed vessels for 3 days was found to result in a loss of setting quality, but this loss was less than that taking place in large bulks of pomace exposed to the air. Approximately half of the loss in jelly value occurred when twice-pressed pomace was stored, either in slab or disintegrated form, in one day. Sulfur dioxide in all concentrations from 250 to 1500 p.p.m. had a preservative effect on the pomace, and the loss in jelly quality of pomace stored with sulfur dioxide was found to be slight up to 7 days, but became considerable after 13 days when mold growth became excessive.[870] To avoid loss of pectin quality apple pomace is dried immediately after pressing. Changes in pectin quality may also occur during the storage of dried pomace. These changes have been found to be caused by moisture and were not enzymic in character.[871] Pomace stored with 33% moisture or more lost water and soluble pectin and developed mold. No mold developed in artificially infected pomace containing less than 20% moisture.

Purification of Pomace. Apple pomace contains considerable amounts of soluble carbohydrates and minerals which are usually removed before the pectin is extracted. A considerable increase in the yield of jelly units, combined with a lower weight of pomace, has been found possible on removal of starches, sugars, salts, and coloring and flavoring substances from pressed, juice-free pomace before drying. Starch may be removed by heating the pomace with suitable quantities of water to render the starch hydrolyzable, followed by treatment with diastatic enzymes. The leaching liquid is then removed by pressing before final drying.[872-874] Pectin obtained from pomace treated in this manner possesses greater clarity and is more readily concentrated or dried because of its lower content of sugars and starch. The value of treatment with diastatic enzymes depends on the condition of the

[870] V. L. S. Charley, L. F. Burroughs, M. E. Kieser, A. Pollard, and J. Steadman, *Ann. Rept. Agr. and Hort. Research Sta., Long Ashton, Bristol, 1942,* 89; *Fruit Products J., 24* (1), 4 (1944).

[871] Z. I. Kertesz and E. L. Green, *N. Y. Agr. Expt. Sta. Tech. Bull.,* 179, 1931, pp. 3–14.

[872] G. L. Baker and R. Kneeland, *Ind. Eng. Chem., 27,* 92 (1935).

[873] G. L. Baker, *Delaware Agr. Expt. Sta. Bull.,* 204 (Tech. No. 18), 1936.

[874] G. L. Baker and M. W. Goodwin, U. S. Pat. No. 2,088,458, July 27, 1947; *Fruit Products J., 17* (2), 37, 55 (1937).

fruit at time of pressing and the treatment is of little value when the apples have ripened to the point of complete disappearance of the starch.

The pectin may be more effectively extracted and a larger number of jelly units obtained from pomace that is more finely ground than that obtained from commercial driers. After grinding not only sugars but all other soluble constituents appear in the leach water in greater amounts. The maximum amount of fermentable substances was found to appear in leach water when the pomace had been reduced to a particle size which allowed the diastatic enzymes to hydrolyze all the starches present.[875]

Pectin Extraction. Pectin cannot be extracted in good yield from fresh pomace because of the slimy character of the press cake, and therefore dried pomace is used almost exclusively for this purpose. The dried pomace holds (imbibes) less water and does not break up during the extraction, thus making pressing and filtration easier. It has the added advantage that it is relatively stable during storage. Crude dried pomace is given a preliminary leaching with water to remove soluble carbohydrates, salts and flavoring and coloring substances, and to reduce the spray residue content. The leached and drained pomace is then subjected to extraction with water containing an acid. The extraction process constitutes a restricted acid hydrolysis of the protopectin remaining in the leached pomace into soluble pectin. This same hydrolytic action tends to hydrolyze pectin further into smaller units of inferior jelly value and it is important that the hydrolysis be so regulated that a maximum amount of protopectin is brought into solution while at the same time avoiding further hydrolysis of the solubilized pectin.

Pectin may be extracted under a great variety of conditions involving temperatures in the range from 160° to 210°F., acidities from *p*H 1.6 to 3.0, and extraction periods of from 15 minutes to two hours. Longer extraction periods are necessary when less acid is used and one hour at boiling temperature has been recommended for apple pomace when acidity of the extracting medium ranged from *p*H 2.8 to 3.2.[876] Increased yields of jelly units have been found possible when

[875] G. L. Baker and M. W. Goodwin, *Fruit Products J., 17* (8), 232 (1938).
[876] R. M. McCready and W. D. Maclay, *Western Canner and Packer, 36* (2), 37, 41 (1944).

polyphosphates are added to the extracting medium.[879] The action of the polyphosphates is to form soluble complexes with metallic ions such as calcium which hold pectin as insoluble salts during extraction. Ion exchange resins have also been employed to remove metallic ions before extraction of pectin.[880]

The pectin extract is removed from the spent pomace by pressing in racks and cloths as described for apple juice (Chapter XII), and the extract is further purified by natural sedimentation or centrifuging, followed by filtration using a filter aid. Filtration of the extract is one of the most difficult operations in pectin manufacture because of the viscous, colloidal nature of pectin in water solution. The purity and clarity of the final product depend upon the success of the filtration step. If starches have not been previously removed from the pomace the extract may be turbid and require treatment with diastatic enzymes before a clear product can be obtained. Hydrolysis of starch is conducted most effectively at a temperature of 86°F. and *p*H between 3.2 and 3.5.[881] Care is taken that the enzyme preparation used does not have pectin-decomposing activity. Products of light color may be produced by treating the dilute extract with sulfur dioxide gas or with decolorizing carbon before filtration and concentration. The clarified extact is concentrated under vacuum to avoid decomposition of the pectin.

The pectin may be used in the form of a concentrated extract in the preparation of jellies, jams, and other pectin products, or it may be dried. It is convenient to standardize liquid extacts at a jelly grade of 5. The concentrate may then be flash pasteurized at 185°F. and hermetically sealed in suitable containers. The dried product occupies less space, is more economical to ship, and is resistant to decomposition by microoganisms. Special care must be taken to avoid lumping when it is redissolved for use. Several methods have been developed for the preparation of dried pectin. The concentrated extract may be evaporated in spray or drum driers or the pectin may be precipitated with ethyl alcohol, aluminum hydroxide, or other suitable agents. The precipitated pectin is pressed to remove excess liquid and then air dried. Unless the dried product is obtained in the form of flakes or thin sheets it is ground before packaging. The dried product is graded on the

[879] G. L. Baker and C. W. Woodmansee, *Fruit Products J., 23* (6), 164, 185 (1944).
[880] P. B. Myers and A. H. Rouse, U. S. Pat. No. 2,323,483, July 6, 1943.
[881] G. L. Baker, *Delaware Agr. Expt. Sta. Bull.,* 204 (Tech. No. 18), 1936.

basis of its jelling power and marketed on the basis of this grade or it may be standardized to a predetermined grade by mixing with dry dextrose or sucrose. Jelly grade is determined on the basis of trial jellies made under standardized conditions. Several instruments have been developed for measuring the firmness of test jellies and finished fruit jellies and jams.[882-886]

Concentrated liquid extracts and dried products prepared without precipitation contain acids used in their preparation as well as soluble solids contributed by the pomace. When such products are to be used in the preparation of food products it is necessary that the extracting acid be suitable for food use. The soluble solids present in these products may not be included in the calculation of total fruit solids, even when the pectin is used in preparing apple jelly or jam.

Pectin from Other Apple Sources. Apple thinnings, the immature fruit removed from the tree during thinning, have been investigated as a source of pectin.[887-889] Apple thinnings are high in pectin and yields up to 1.2% of 280-grade pectin have been reported. Preparation of pectin from thinnings is complicated by the presence of considerable amounts of starch in the immature fruit but products of satisfactory quality may be prepared by using suitable processes. The practicability of using thinnings as a commercial source of pectin depends on the cost involved in collection and shipping of this material to a central processing plant. This has not been found practical under ordinary conditions.

Pectin Utilization. Commercial utilization of pectin is limited mainly to the preparation of fruit jellies and preserves. Considerable interest has been shown in the development of new uses for pectin, however. Of particular interest are the low-ester pectins prepared by the controlled demethylation of this material. These substances are capable of forming gels in the presence of metallic salts such as calcium without the necessity of a high concentration of sugar and acid required for fruit jellies. Low-ester pectins may be prepared from

[882] L. W. Tarr, *Delaware Agr. Expt. Sta. Bull.*, 142 (Tech. No. 5), 1926.
[883] H. C. Lockwood and R. S. Hayes, *J. Soc. Chem. Ind., 50,* 145T (1931).
[884] G. L. Baker, *Fruit Products J., 17* (11), 329 (1938).
[885] R. E. Cox and R. H. Higby, *Food Inds., 16,* 441, 505 (1944).
[886] H. S. Owens, O. Porter, and W. D. Maclay, *Food Inds., 19,* 606, 746, 748, 750 (1947).
[887] H. W. Gerritz, *Ind. Eng. Chem., 27,* 1458 (1935).
[888] Z. I. Kertesz, *Farm Research,* N. Y. Agr. Expt. Sta., Jan., 1937.
[889] G. L. Baker and M. W. Goodwin, *Fruit Products J., 18* (2), 56, 59 (1938).

pectin by demethylation with suitable enzymes, or by controlled hydrolysis either with acids or alkalis,[890-894] and promise to become useful in the commercial production of low-solids gels for food use. A number of products such as salads, consommés, aspics, and puddings have been successfully prepared and canned on an experimental scale.[895,896] A simplified enzymic procedure has been developed for preparing low-ester pectin from apple pomace.[897] The use of pectic preparations in pharmaceutical pastes and ointments,[898] as substitutes for agar in bacteriological gels,[899] and as emulsifying agents[900] has been investigated. Salts of pectinic acids have been proposed as ingredients, with sugar, in frozen fruits for the purpose of reducing juice drainage during thawing and improvement in appearance.[901] Pectin has also been found to be a practical source of *galacturonic acid*.[902-906]

3. POMACE AS INSECT BAIT

Dried apple pomace has a natural attraction for many insects and an increasing volume of this product is being used for insect baits. Little technical information is available on this subject but the product appears to have added value if some peeling and core material is included in addition to regular pomace. Suitable insecticides, such as arsenicals, are mixed with the pomace before use.

[890] G. L. Baker and M. W. Goodwin, *Delaware Agr. Expt. Sta. Bull.*, 234 (Tech. No. 28), 1941; 246 (Tech. No. 31), 1944.
[891] G. L. Baker and M. W. Goodwin, *Food Inds., 14* (9), 53, 99 (1942).
[892] C. H. Hills, J. W. White, Jr., and G. L. Baker, *Proc. Inst. Food Technol., 1942*, 47.
[893] R. M. McCready, H. S. Owens, and W. D. Maclay, *Food Inds., 16,* 794, 864, 865, 906 (1944).
[894] H. S. Owens, R. M. McCready, and W. D. Maclay, *Ind. Eng. Chem., 36,* 936 (1944).
[895] C. W. Kaufman, E. R. Fehlberg and A. G. Olson, *Food Inds., 14,* (12), 57, 109 (1942); *15* (1), 58 (1943).
[896] V. E. Pollari, W. G. Murray, and G. L. Baker, *Fruit Products J., 25* (1), 6 (1945).
[897] H. H. Mottern and C. H. Hills, *Ind. Eng. Chem., 38,* 1153 (1946).
[898] W. D. Maclay, A. D. Shepherd, and H. Lotzkar, *J. Am. Pharm. Assoc., Sci. Ed., 33,* 113 (1944).
[899] R. M. McCready, H. S. Owens, and W. D. Maclay, *Science, 97,* 428 (1943).
[900] H. Lotzkar and W. D. Maclay, *Ind. Eng. Chem., 35,* 1294 (1943).
[901] R. E. Buck, G. L. Baker, and H. H. Mottern, *Food Inds., 16,* 113, 147 (1944).
[902] F. Ehrlich, *Abderholden's Handbuch der Biologischen Arbeitsmethoden,* Abt. 1, Teil II, 1617 (1936).
[903] H. H. Mottern and H. L. Cole, *J. Am. Chem. Soc., 61,* 2701 (1939).
[904] I. A. Manville, F. J. Reithel, and P. M. Yamada, *ibid., 61,* 2972 (1939).
[905] W. W. Pigman, *J. Research Natl. Bur. Standards, 25,* 301 (1940).
[906] E. Rietz and W. D. Maclay, *J. Am. Chem. Soc., 65,* 1242 (1943).

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TABLE A-1. Apples, Commercial Crop (in Thousand Bushels)[a]

Area and State	Production[b]			
	Average 1938–1947	1947	1948	Preliminary 1949
Eastern States				
North Atlantic				
Maine	717	930	949	1,087
New Hampshire	721	838	612	1,056
Vermont	626	799	774	1,089
Massachusetts	2,488	2,864	2,194	3,842
Rhode Island	218	187	143	279
Connecticut	1,256	1,273	824	1,640
New York	14,620	15,045	11,750	20,090
New Jersey	2,655	1,935	1,364	3,124
Pennsylvania	7,598	6,612	4,520	9,680
Total North Atlantic	*30,899*	*30,483*	*23,130*	*41,887*
South Atlantic				
Delaware	714	334	382	624
Maryland	1,603	938	928	1,389
Virginia	9,664	5,072	8,240	7,820
West Virginia	3,946	2,820	2,750	3,720
North Carolina	958	768	976	448
Total South Atlantic	*16,885*	*9,932*	*13,276*	*14,001*
Total Eastern States	*47,784*	*40,415*	*36,406*	*55,888*
Central States				
North Central				
Ohio	3,875	3,038	1,936	5,446
Indiana	1,344	1,489	1,018	1,715
Illinois	3,045	4,187	2,401	4,176
Michigan	6,840	6,400	4,830	11,735
Wisconsin	704	799	642	724
Minnesota	186	272	53	357
Iowa	175	108	131	173
Missouri	1,229	1,630	865	1,548
Nebraska	193	88	102	120
Kansas	626	755	376	808
Total North Central	*18,217*	*18,766*	*12,354*	*26,802*
South Central				
Kentucky	269	276	250	433
Tennessee	339	396	273	452
Arkansas	575	756	567	706
Total South Central	*1,183*	*1,428*	*1,090*	*1,591*
Total Central States	*19,400*	*20,194*	*13,444*	*28,393*

Table continued

TABLE A-1 (*continued*)

Area and State	Production[b] Average 1938–47	1947	1948	1949
Western States				
Montana	258	238	214	170
Idaho	2,092	2,075	1,450	1,743
Colorado	1,524	1,568	1,395	1,628
New Mexico	717	620	750	788
Utah	477	505	450	428
Washington	28,034	33,480	25,760	31,820
Oregon	2,871	2,864	2,668	3,010
California	7,959	11,082	5,870	9,520
Total Western States	*43,932*	*52,432*	*38,557*	*49,107*
Total 35 States	*111,115*	*113,041*	*88,407*	*133,388*

[a] Table from Crop Reporting Board, U. S. D. A., 1949. Estimates of the commercial crop refer to the total production of apples in the commercial apple areas of each state

[b] For some states in certain years, production includes some quantities unharvested on account of economic conditions.

TABLE A-2. Apples, Production in Specified Countries (in Thousand Bushels)[a]

Continent and country	Average 1935–1939	1941	1942	1943	1944	1945[b]
North America						
United States	127,311	122,585	128,700	89,050	124,754	64,400
Canada	13,650	10,055	12,171	12,171	16,715	7,205
Mexico	1,231	2,021	1,729	1,769	1,790	1,286
Total	*142,192*	*134,661*	*142,600*	*102,990*	*143,259*	*72,891*
Europe						
Austria	15,140[c]	(10,638)	(7,300)	(9,550)	(10,400)	(8,700)
Belgium	(1,200)	—[d]	—[d]	—[d]	—[d]	8,000
Bulgaria	1,064[c]	2,798	3,301	(3,300)	(3,300)	3,209
Czechoslovakia	9,034[c]	4,605	6,111	4,061	5,094	2,642
Denmark	1,182[c]	5,971	3,588	5,626	5,282	(4,534)
Estonia	1,563	(1,530)	(1,160)	(1,820)	(1,710)	(1,470)
Finland	1,023[c]	(1,460)	(905)	(1,875)	(1,120)	(1,075)
France						
Dessert and cooking	10,499	3,096	6,790	8,211	18,958	6,991
Cider	153,973	14,825	74,428	38,196	212,900	(89,000)
Germany	52,647	36,743	(25,151)	(33,000)	(36,000)	(30,000)

Table continued

TABLE A-2 (*continued*)

Continent and country	Average 1935–1939	1941	1942	1943	1944	1945[b]
Greece	374	(400)	(300)	(500)	(350)	446
Hungary	2,313[c]	—[d]	—[d]	—[d]	—[d]	690
Italy	13,107	16,337	11,083	20,274	14,701	13,743
Luxembourg						
Dessert and cooking	193	120	250	300	710	260
Cider	93	20	110	60	310	130
Netherlands	3,820[c]	(1,300)	(2,900)	(3,500)	(8,100)	(3,000)
Norway	1,080	(1,120)	(850)	(1,330)	(1,250)	(350)
Rumania	31,983[c]	—[d]	—[d]	—[d]	—[d]	—[d]
Spain	5,411[c]	5,739	(5,000)	(6,000)	(6,000)	(3,600)
Sweden	(2,000)	(2,075)	1,572	2,473	(2,300)	(2,000)
Switzerland	16,452	21,127	16,994	29,854	32,150	(16,000)
Turkey	5,139	(5,000)	(3,500)	(6,500)	(4,800)	(3,800)
United Kingdom						
Dessert and cooking	10,597	7,607	17,519	15,279	15,675	(12,500)
Cider	3,427	1,479	2,749	3,645	6,146	(3,500)
Yugoslavia	6,913	—[d]	—[d]	—[d]	—[d]	—[d]
Total (excluding cider)	*192,734*	*172,266*	*160,303*	*196,303*	*211,730*	*145,711*
Total	*350,227*	*188,590*	*238,051*	*238,204*	*431,086*	*238,341*
Other countries						
Argentina	1,286	3,904	6,632	5,746	7,771	6,990
Chile	940[c]	596	367	550	550	(600)
South Africa	(950)	1,400	1,000	1,000	729	833
Korea	3,220	5,166	—[d]	—[d]	—[d]	—[d]
Japan	7,624	9,304	—[d]	—[d]	—[d]	—[d]
Palestine	65	112	161	152	(150)	(150)
Australia	9,131	9,620	8,620	12,710	7,649	(10,000)
New Zealand	2,961	1,890	2,344	2,609	2,300	2,250
Total	*26,177*	*31,586*	*34,324*	*38,567*	*38,567*	*37,823*
World total (excluding cider)	*361,103*	*338,513*	*337,688*	*337,775*	*390,538*	*256,425*
World total	*518,596*	*354,837*	*414,975*	*379,676*	*609,894*	*349,055*

[a] From U. S. D. A. Bureau of Agricultural Economics (Office of Foreign Agricultural Relations Committee). Compiled from official sources. Figures in parentheses are estimates of the Office of Foreign Agricultural Relations. The harvests of Northern Hemisphere countries are for the year shown and are combined with the harvest in Southern Hemisphere countries of the following year.

[b] Preliminary. [c] Partly estimated. [d] Included in total.

TABLE A-3. Commercial Apple Production (in Thousand Bushels) by Varieties for Selected States and Areas 1943, 1944, and 1945[a]

Area and state	1943	1944	1945	1943	1944	1945	1943	1944	1945	1943	1944	1945	1943	1944	1945
North Atlantic		*McIntosh*			*Northern Spy*			*R. I. Greening*			*Cortland*			*Baldwin*	
New England....	3230	3,707	637	235	237	44	90	109	21	203	256	79	722	1187	310
New York.....	4080	5,273	605	680	850	151	1770	2041	130	950	1,191	130	1540	1870	367
New Jersey.....	162	188	78	—	—	—	20	20	13	—	—	—	20	20	26
Pennsylvania....	203	273	74	76	91	17	10	10	8	101	182	49	127	187	49
South Atlantic		*Paragon*			*Delicious*			*G. Delicious*			*Grimes*			*York*	
Virginia.....	168	583	63	168	1503	220	112	292	157	168	437	157	2290	3645	1258
West Virginia....	41	174	32	123	436	163	61	87	65	184	479	146	696	1133	650
Other states.....	129	263	47	193	883	142	125	253	79	104	128	81	239	349	208
Central States		*Grimes*			*Stayman*			*Rome*			*McIntosh*			*Jonathan*	
Ohio.....	121	324	98	218	755	59	412	809	206	97	270	30	340	755	118
Michigan.....	271	374	68	65	92	4	—	—	—	860	1,166	150	1319	1595	225
Other states.....	497	472	524	267	263	223	186	250	100	191	243	103	1155	1187	1469
Western States		*Delicious*			*G. Delicious*			*Jonathan*			*Winesap*			*Newtown*	
Washington.....	9890	14,499	12,970	345	556	513	1495	2468	1563	8510	10,397	8075	345	309	256
California.....	696	492	647	—	—	—	174	184	277	714	123	185	2958	1658	2864
Other states.....	1214	1,834	2,033	7	19	25	1069	1989	1363	309	577	373	1177	1475	1071

Area and state	1943	1944	1945	1943	1944	1945	1943	1944	1945	1943	1944	1945
North Atlantic		*Delicious*			*Ben Davis*			*Wealthy*			*Rome*	
New England....	337	421	53	21	32	6	160	147	73	17	23	14
New York.....	475	680	86	750	1021	65	827	680	194	500	510	108
New Jersey.....	183	230	168	10	10	6	81	20	39	426	334	272
Pennsylvania....	456	728	234	152	273	37	254	182	49	456	1001	297
South Atlantic		*Ben Davis*			*Stayman*			*Winesap*			*Rome*	
Virginia.....	335	729	94	783	2041	283	838	2624	315	56	146	32
West Virginia....	184	348	98	266	610	81	61	130	49	102	174	65
Other states.....	55	126	15	382	1057	157	72	148	22	105	190	84
Central States		*Delicious*			*G. Delicious*			*Ben Davis*			*Baldwin*	
Ohio.....	194	593	59	121	108	59	49	54	10	250	432	118
Michigan.....	312	686	12	71	107	63	106	130	12	335	259	81
Other states.....	605	539	443	820	773	796	217	292	115	10	14	8
Western States		*Stayman*			*Gravenstein*			*Rome*				
Washington.....	299	370	385	—	—	—	1610	1944	1666			
California.....	—	—	—	2262	1782	2680	435	369	462			
Other states.....	75	80	63	63	91	40	631	974	1223			

[a] From U. S. D. A. Bureau of Agricultural Economics.

TABLE A-4. Apples: Production, Value, Quantities Processed, and Foreign Trade, United States, 1929–1944

Year	Apples, total crop				Apples, commercial crop[a]			
	Total production, 1000 bu.	Production having value, 1000 bu.	Season average price per bushel received by farmers, dollars	Farm value, 1000 dollars	Total production, 1000 bu.	Production having commercial value, 1000 bu.	Season average price per bushel received by farmers, dollars	Farm value, 1000 dollars
1929	126,433	—	—	—	—	-	–	
1929	135,102	135,102	1.39	187,581	—	–	—	
1930	156,623	156,623	1.03	161,677	—	–	–	-
1931	205,404	203,304	0.64	129,230	—	—	—	—
1932	146,809	142,589	0.61	86,886	—	—	—	—
1933	148,640	144,040	0.79	113,908	—	—	—	—
1934	128,203	126,858	0.89	112,308	106,005	104,757	0.88	91,667
1935	174,407	164,778	0.73	120,066	140,398	131,843	0.72	94,797
1936	116,827	115,910	1.04	121,028	98,025	97,295	1.04	101,023
1937	201,459	185,906	0.67	123,818	153,169	141,035	0.64	90,757
1938	125,440	121,249	0.83	100,808	105,718	101,850	0.82	83,851
1939	—	—	—	—	139,247	124,729	0.64	80,113
1940	—	—	—	—	111,439	106,812	0.80	85,283
1941	—	—	—	—	122,585	120,005	0.96	115,051
1942	—	—	—	—	128,700	119,889	1.37	163,740
1943	—	—	—	—	89,050	89,050	2.39	212,744
1944[b]	—	—	—	—	124,754	122,529	2.16	264,695

[a] Estimates of the commercial crop refer to the production of apples in the commercial apple areas of each state and include fruit produced for sale to commercial processors as well as for sale for fresh consumption. Since 1938, official estimates of apple production have been restricted by law to the commercial crop.

[b] In 1944, includes 2,425,000 bushels frozen and 16,782,000 bushels for other purposes, mostly vinegar, cider, and juice.

[c] Compiled from Monthly Summary of Foreign Commerce of the U. S. Dept. of Commerce.

TABLE A-4(*Continued*). APPLES: PRODUCTION, VALUE, QUANTITIES AND PROCESSED, FOREIGN TRADE, UNITED STATES, 1929–1944

Quantities processed			Foreign trade, year beginning July[c,d]					
			Domestic exports			Imports, fresh and dried, in terms of fresh, 1000 bu.	Net exports in terms of fresh fruit[g]	Year
Canned, 1000 bu.	Dried, 1000 bu.	Other,[b] 1000 bu.	Fresh,[e] 1000 bu.	Dried in terms of fresh,[f] 1000 bu.	Canned in terms of fresh, 1000 bu.			
—	—	—	—	—	—	—	—	1929
—	—	—	10,279	3466	836	312	14,269	1929
—	—	—	20,340	5559	640	103	26,437	1930
—	—	—	18,030	4602	695	82	23,246	1931
—	—	—	13,754	5690	748	6	20,186	1932
—	—	—	12,261	6297	439	13[h]	18,986	1933
7,524	7106	8,838	8,062	3571	561	28	12,166	1934
7,732	9146	14,176	12,239	5032	900	5	18,166	1935
7,853	6698	7,386	6,755	3343	503	36	10,564	1936
9,266	8646	15,877	10,958	4062	497	5	15,511	1937
4,807	6347	8,783	12,071	5112	625	47	17,761	1938
9,110	8172	16,043	3,216	2490	538	107	6,137	1939
7,007	4268	11,070	867	514	29	588	822	1940
12,338	6165	15,884	1,730	2297	73	11	4,089	1941
11,426	7376	16,300	435	1611	24	541	1,529	1942
6,662	6692	10,961	317	2468	157	178	2,764	1943
9,323	6895	19,207	1,287	1654	21	2396	567	1944[i]

[d] Dried and canned are converted to terms of fresh apples on following basis: 1 pound of dried is equivalent to about 7 pounds of fresh through 1942 (beginning 1943, 1 pound of dried is equivalent to 8 pounds of fresh); 1 pound of canned is equivalent to about 2 pounds of fresh; 48 pounds of fresh equal 1 bushel. No reexports reported.

[e] Excludes apple waste.

[f] Beginning January 1933, includes apple waste, not separately reported prior to this date.

[g] Total exports (domestic plus foreign) minus imports. Beginning 1933 domestic exports minus imports for consumption.

[h] Beginning 1933–1934, imports for consumption.

[i] Preliminary.

TABLE A-5. The Production and Utilization of Apples, 1947–1948 (in Thousands of Bushels)[a]

Year	Total production	Fresh fruit sales	Canned	Dried	Frozen	Vinegar, juice, jelly, and other uses
1947	113,041	76,825	9,003	4,971	737	11,578
1948	88,407	63,384	7,796	2,564	913	8,050

[a] From *The Fruit Situation*, U. S. D. A., Bur. Agr. Economics, TFS-92, 1949.

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